

AIRCRAFT EQUIPMENT DIVISION

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REPORT

SOLID POLYMER ELECTROLYTE (SPE)

FUEL CELL TECHNOLOGY PROGRAM

FINAL REPORT (PHASE IV)

Contract NAS 9-15286, DRL Line Item No. 4

Prepared for

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

(NASA-CR-160159) SOLID POLYMER ELECTROLYTE

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DIRECT ENERGY CONVERSION PROGRAMS

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WILMINGTON, MASSACHUSETTS 01887



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ACKNOWLEDGMENTS

This report summarizes the results of a Solid Polymer Electrolyte fuel cell technology program conducted for the National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Houston, Texas, by the General Electric Company, Direct Energy Conversion Programs, Wilmington, Massachusetts, under Contract NAS 9-15286. The period of performance was February, 1978 through January, 1979.

This work was performed under the guidance of Mr. G.D. Hydrick, Jr., Program Manager for the Power and Propulsion Branch of NASA/Lyndon B. Johnson Space Center. The overall program was directed by J.F. McElroy, Project Engineer, General Electric Company, Direct Energy Conversion Programs.



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1.0 SUMMARY

The overall objectives of the Phase IV Solid Polymer Electrolyte Fuel Cell Technology Program were to:

- Establish fuel cell life and performance at temperatures, pressures and current densities significantly higher than those previously demonstrated.
- Provide the ground work for a space energy storage system based on the solid polymer electrolyte technology (i.e., regenerative H_2/O_2 fuel cell).
- Design, fabricate and test evaluate a full-scale single cell unit.

During this phase, significant progress was made toward the accomplishment of these objectives.

In the area of fuel cell life, for instance, the 0.7 Ft^2 cell stack demonstrated nearly 6000 hours of operation at intermediate current densities, temperatures, and low pressures. A 0.05 Ft^2 laboratory-size cell demonstrated nearly 4000 hours of stable life at high pressure and high current density. Both of these cells utilized the conductive cathode wetproofing, a configuration which provides significant performance and weight benefits when scaled to large-size cells. In addition, design deficiencies were uncovered in timely fashion during the endurance life task, such that introduction into the 1.1 Ft^2 design was possible.

In regard to electrical energy storage for space applications, a task to assess regenerative fuel cell performance optimization was successfully concluded. During this effort, compromise catalyst combinations were evaluated to identify the optimum electrical energy storage efficiency obtainable from a single electrochemical device (i.e., involving H_2/O_2 fuel cell function and H_2O electrolysis function both being performed by the same unit). Normally an excellent electrolysis catalyst is a poor fuel cell catalyst and vice versa. The optimum H_2/O_2 regenerative performance was also compared to demonstrated hydrogen/halogen regenerative fuel cells to provide the available regenerative fuel cell options.

As stated above, during this phase the advances previously demonstrated in laboratory-size hardware were introduced into a 1.1 Ft^2 (active area) cell design. Hardware was fabricated, assembled and non-operationally checked for leakage, flow and electrical characteristics. Initial performance of this single cell unit has shown performance levels equivalent to those obtained in laboratory-sized 3" X 3" cells. The continued success of this unit is demonstrating that the technology is sufficiently developed for multi-cell and reactor stack fabrication and test evaluation.

An additional objective which developed during the course of the Phase IV activities, was the evaluation of various solid polymer electrolyte fuel cell configurations for potentially enhancing the space shuttle capabilities.



Projections were completed for fuel cells with high output voltage, high peak power and a high degree of voltage regulation. It is hoped that these projections will be useful to NASA in their future program planning.

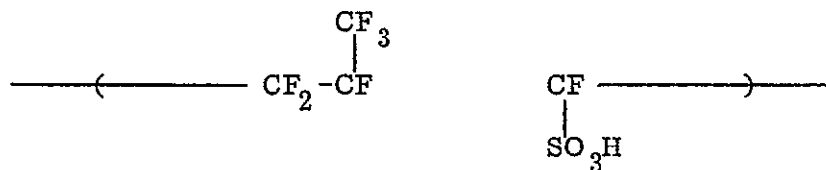


2.0 TECHNICAL BACKGROUND

2.1 General Background

The Solid Polymer Electrolyte fuel cell technology was first developed into a viable product in 1960. Over the past 19 years, improvements in both the Solid Polymer Electrolyte and the electrode technologies resulted in an increase in the field of applications to include electrolysis systems, oxygen concentrators and regenerative fuel cells. All four electrochemical devices utilize the same basic Solid Polymer Electrolyte and electrode components. Thus, the experience gained from one application can be used in the further improvement of the other devices.

The heart of these devices is the Solid Polymer Electrolyte, which is a plastic film approximately 10 mils thick, fabricated from ion exchange material. The material currently used as the Solid Polymer Electrolyte has a chemical structure as follows:



This material, called Nafion*, is essentially a sulfonated analog of Teflon*, with physical properties very similar to Teflon.

The use of the SPE as the sole electrolyte in an electrochemical system offers the following advantages:

Minimum weight

Immobile and invariant during life

Minimum volume

Ease of handling during assembly

Capability of handling high pressure differentials across the membrane

No tendency to react with CO_2 to form carbonates

2.1.1 Solid Polymer Electrolyte Technology

The Nafion SPE described above is a product of duPont and has been utilized extensively by GE/DECP in electrochemical applications since 1968. This membrane is extremely stable, both physically and chemically, while exhibiting excellent physical and electrochemical properties. The specification of these properties are given below:

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Property	Value
Tensile Strength	> 2500 psi (> 17,235 kN/m ²)
Elongation	> 120%
Burst Strength, Unsupported	> 100 psig (> 689 kN/m ² gauge)
Water Content	25-40 Weight %
Resistivity	> 15 ohm-cm
Life in Electrochemical System (hours)	> 51,000 hours demonstrated to date in fuel cells.
Thermal Stability	> 300°F (> 149°C)

The Nafion Solid Polymer Electrolyte is the latest in a series of GE/DECP membrane systems that included phenol-formaldehyde sulfonic, polystyrene sulfonic, and trifluorostyrene sulfonic acids. The Nafion Solid Polymer Electrolyte was the only membrane that offered the excellent combination of physical and chemical stability required in the electrochemical environments.

The first Nafion Solid Polymer Electrolytes did tend to degrade slowly in an electrochemical environment as evidenced by a slow generation of HF and CO₂ from the operating device. However, this problem has been rigorously researched by both duPont and GE/DECP and has culminated in a stack of 0.38 Ft² (354 cm²) cells that has been operating over 51,000 hours, with a projected life of over 100,000 hours. This stack, designated AFC-6, is currently operating at 70 psia (483 kN/m²) oxygen-side pressure and has been run at 180°F for over 37,000 hours with current densities up to 260 ASF (.28 amps/cm²). The performance exhibited by the stack over its life to date is shown in Figure 1.

2.1.2 Electrode Technology

The GE/DECP electrode structures are thin catalyst layers pressed onto the Solid Polymer Electrolyte surface. The catalyst/Solid Polymer Electrolyte electrode also contains a thin (3-4 mil) (.0762-.1016 mm) current collector screen. In order to prevent water masking of the fuel cell oxygen electrode where product water is formed, a wetproofing film is placed on top of the catalyst/current collector. The performance of these electrode structures has been invariant for over 51,000 hours with performance decay of < 1 μ volt per cell hour.

2.2 Major Fuel Cell Programs

The Gemini spacecraft program marked the first operational use of a Solid Polymer Electrolyte unit. The General Electric Solid Polymer Electrolyte fuel cells used on that program successfully completed all seven spacecraft missions, accumulating a total of 850 hours (5000 stack-hours) of flight operation with an excellent record of performance and reliability. The space-



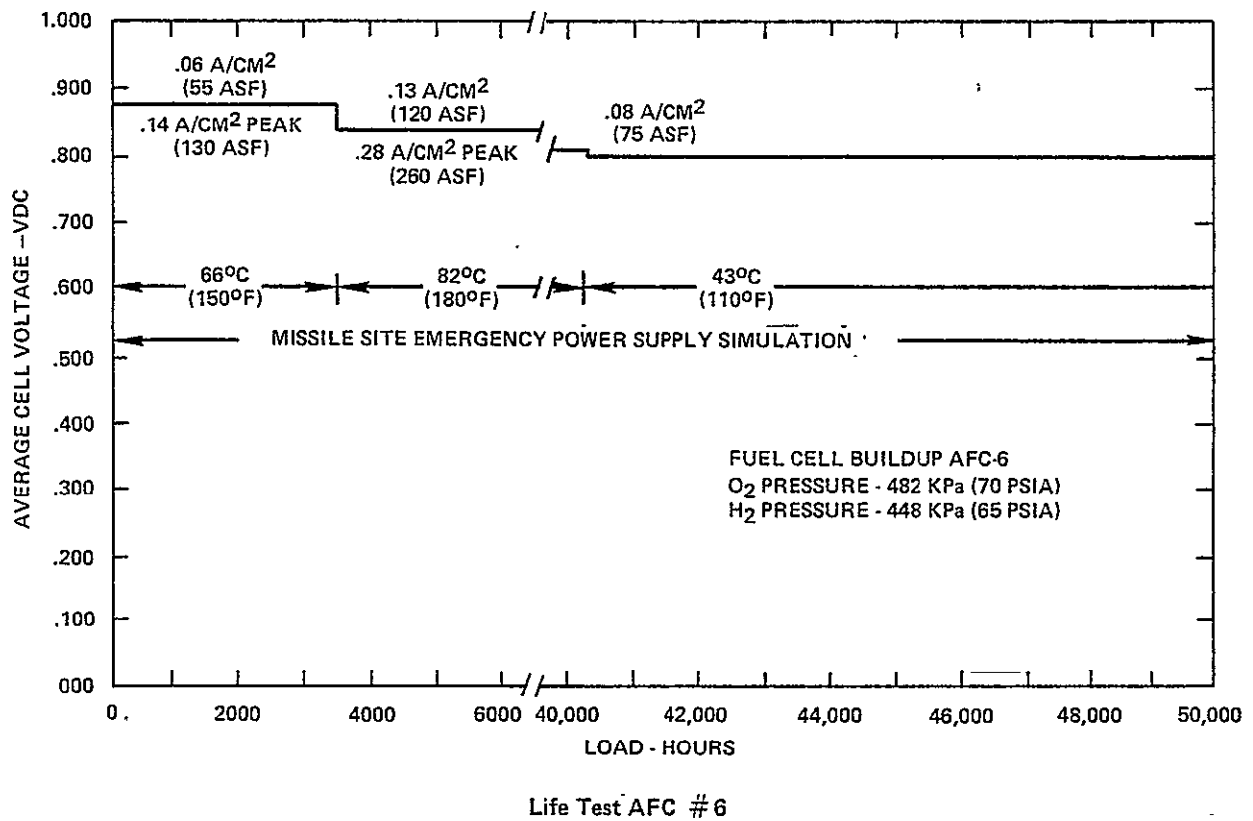


Figure 1.
Average Cell Voltage vs. Load Hours AFC-6



craft system included two 1-KW modules, each containing three 32-cell stacks.

A total of 250 stacks of the production configuration were built during the Gemini program. Most of these were used for reliability, endurance, and over-stress testing, accumulating more than 80,000 stack-hours of operating experience in addition to flight operation.

A second-generation model of this fuel cell design successfully operated in orbit continuously for over 40 days (planned mission of 30 days) on Biosatellite Spacecraft 501. The unit stopped functioning only after the reactants had been depleted.

An additional application, the so-called "back-to-back" cell design concept, in which cathodes of adjacent cells faced each other, was initially developed for Air Force satellites. This concept was continued under NASA's sponsorship.

During the NASA Space Shuttle Technology Development Program, General Electric fabricated and evaluated flightweight fuel cell hardware. Noteworthy is the fact that a 3-cell assembly completed over 6500 hours of life testing, a 38-cell stack accumulated 5000 hours, and a 32-cell stack with ancillary components in a prototype flight configuration achieved 2000 hours of operation.

The technology developed during the Space Shuttle Development Program was then repackaged as a 3 KW fuel cell for the Navy's High Altitude Super-Pressurized Powered Aerostat (HASPA).

Subsequently under sponsorship of NASA's Lewis Research Center, initial development of a new Solid Polymer Electrolyte concept was started. The major feature of this concept was the removal of product water via a dynamic recycling oxygen system, as opposed to the traditional wick and separator approach used since the Gemini Program. The advantages of this concept are in the areas of weight, cost and efficiency.

Figures 2 through 5 display the various products described above. Figure 6 is a graphical presentation of the past 15 years of progress in the Solid Polymer Electrolyte fuel cell technology.



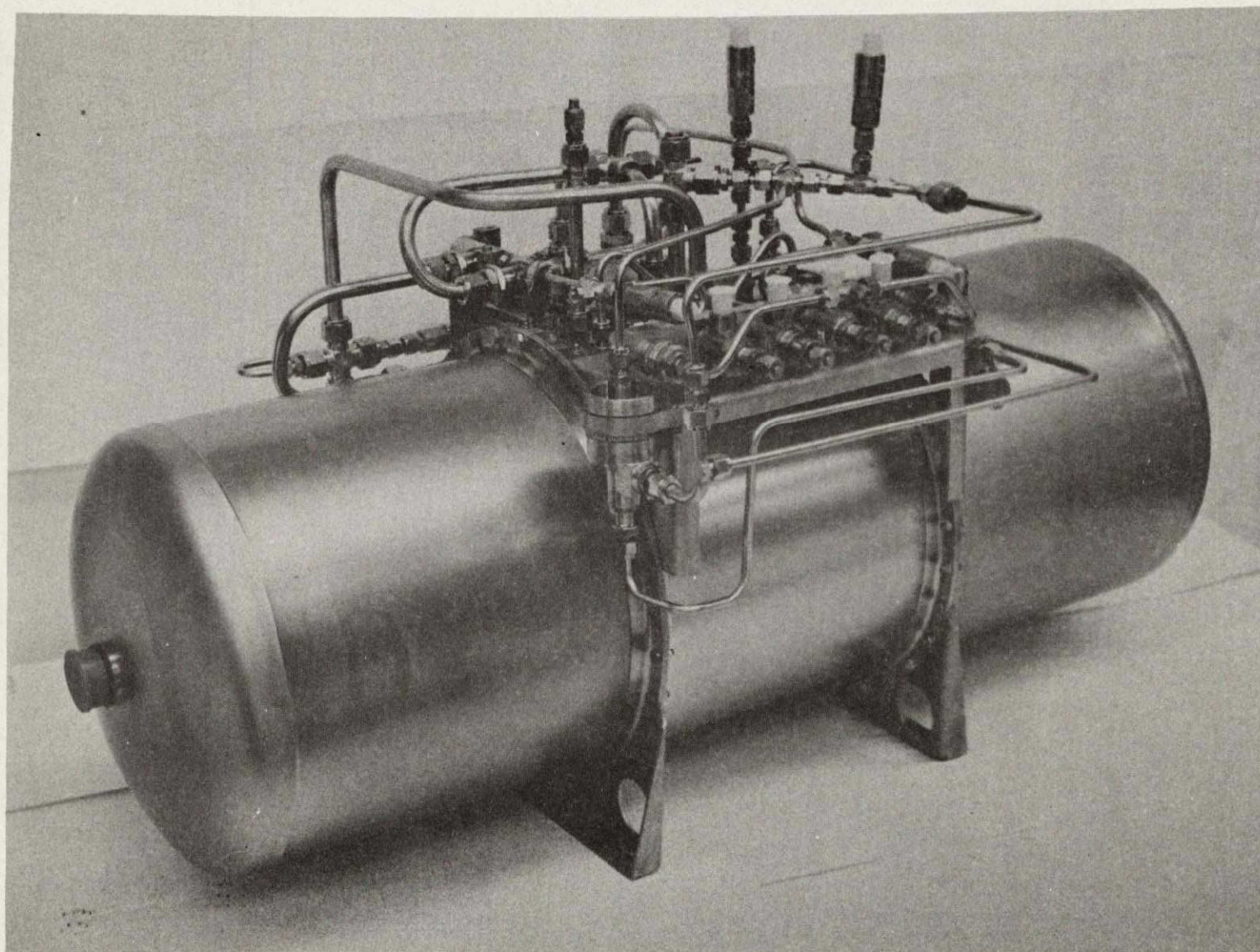
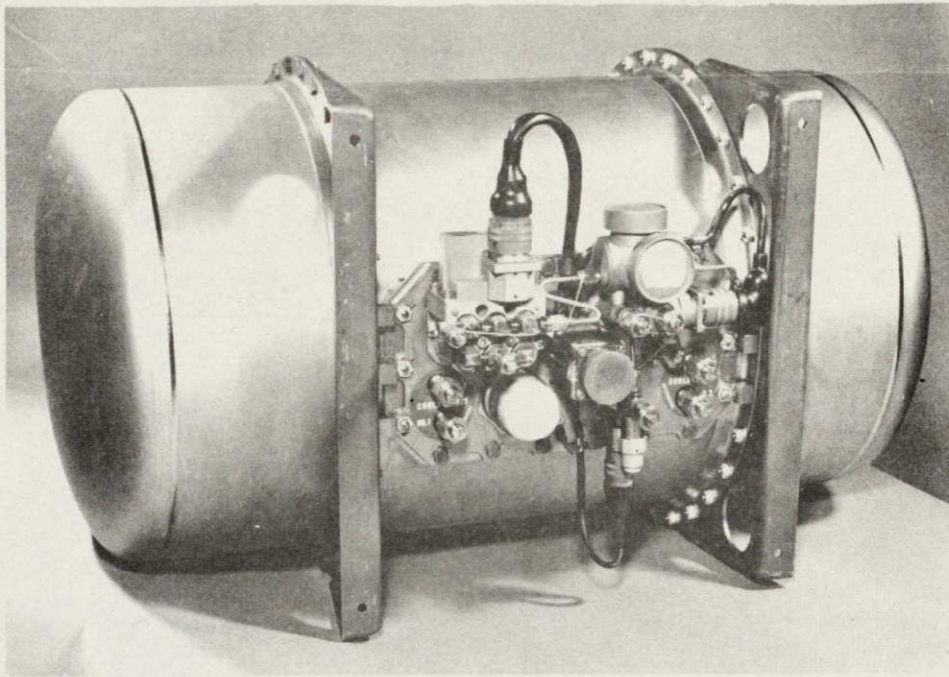


Figure 2. 5 KW Fuel Cell Module with Ancillary Components (NASA/JSC)





One KW Fuel Cell Module for Gemini Spacecraft

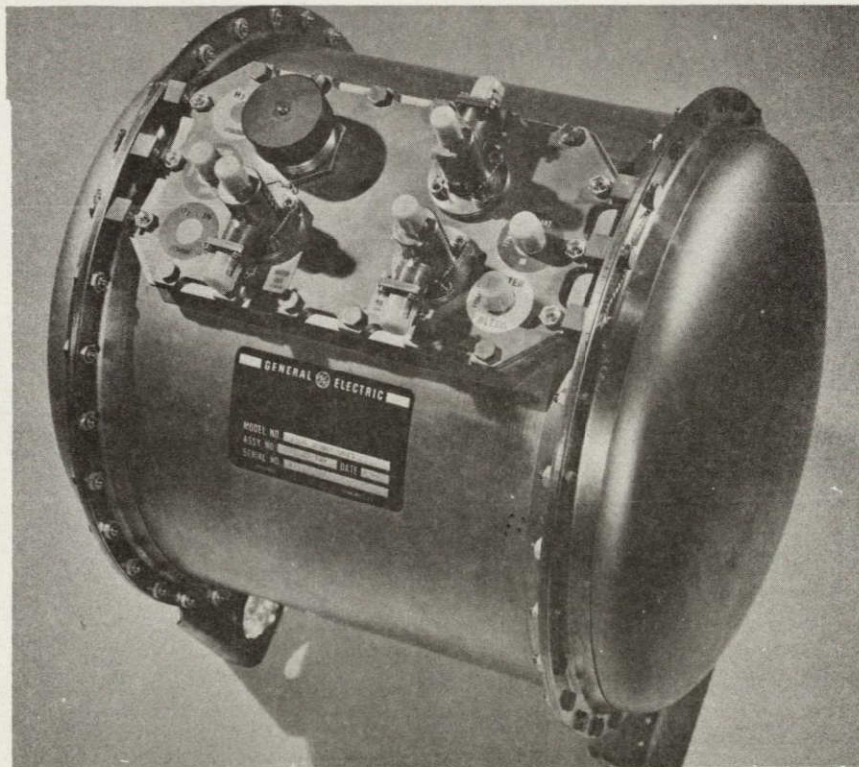


Figure 3. 350-Watt Fuel Cell Module for Biosatellite Spacecraft

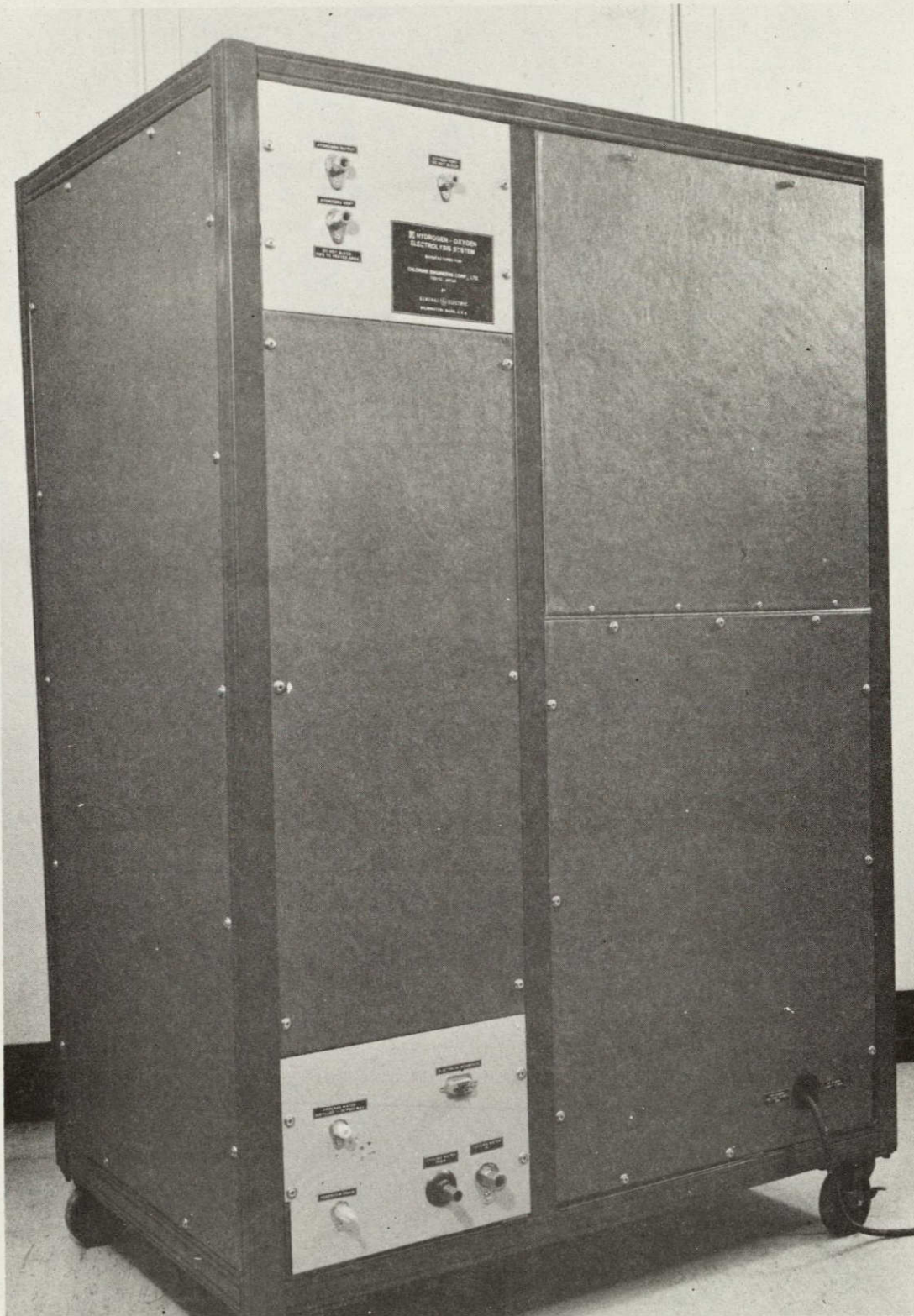
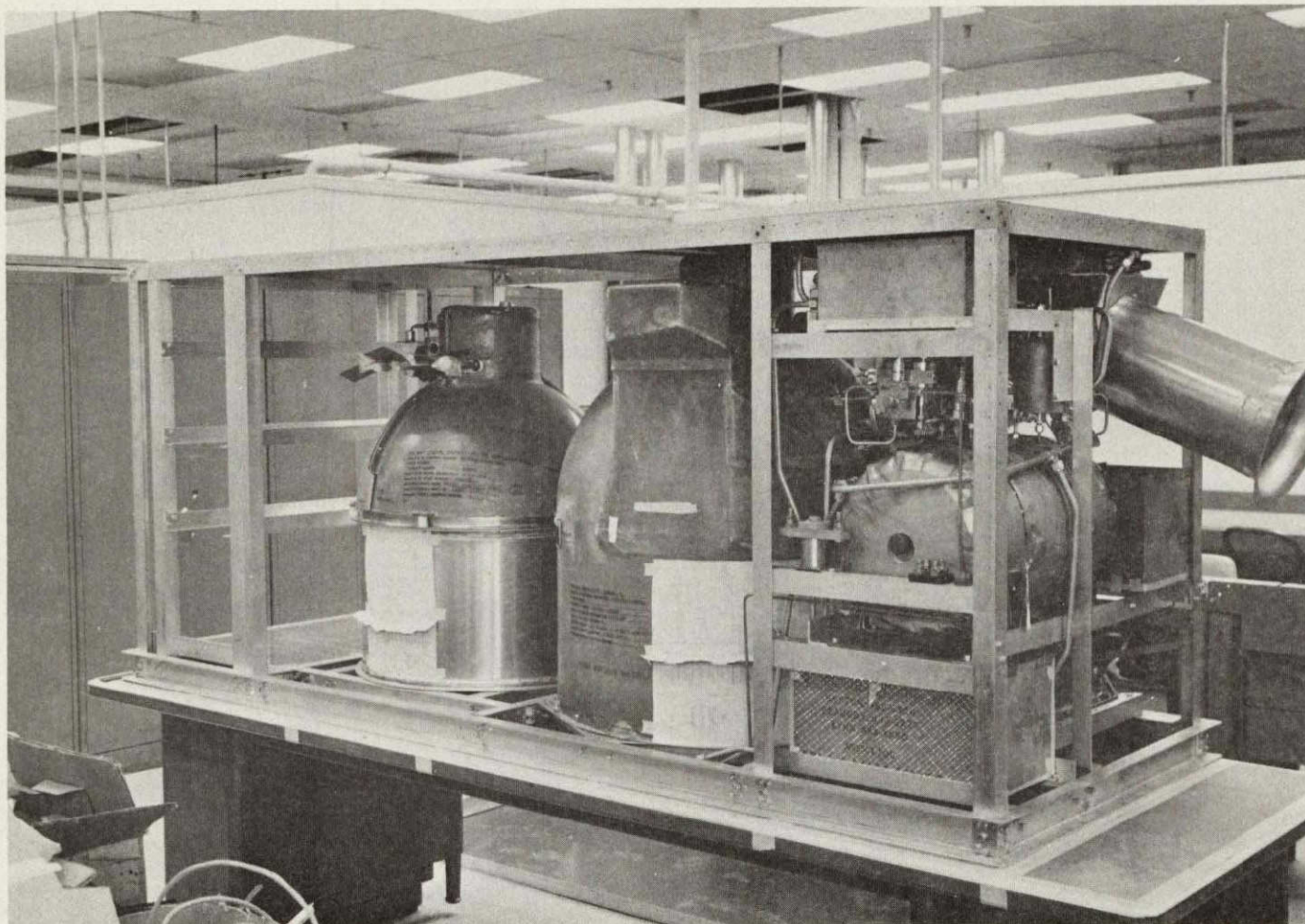


Figure 4. SPE Hydrogen-Oxygen Electrolysis System
Rear View



Complete Fuel Cell Power System, Including Cryogenic Tasks, in the Process of Assembly for U. S. Navy Balloon Program.

The Fuel Cell Performance Remains at Specification Levels Following 1000 Hours Operation and 2 Years Storage.

Figure 5.



3.0 TECHNOLOGY ACTIVITIES

The major efforts of the Phase IV Program were directed in the following technological areas:

- Task 1.0: Continued Evaluation of Laboratory-Size (3" X 3") Cells
- Task 2.0: Regenerative Fuel Cell Testing and Evaluation
- Task 3.0: Full-Scale Cell and Stack Design
- Task 4.0: Single Cell Testing and Evaluation

Figure 7 shows the overall Phase IV Program Milestone Chart.

3.1 Task 1.0 - Continued Testing of Laboratory-Size (3" X 3") Cells and Hardware

During Phase III of this program, a series of endurance and performance tests were begun on laboratory-size cells, the primary purpose of which was to confirm the life and performance characteristics of the IEM fuel cell at temperatures, pressures, and current densities above those previously demonstrated. These tests were continued in Phase IV under Task 1.0, which was expanded beyond the initial effort represented by Sub-Task 1.1, Endurance Evaluations, to include the following:

- 1.2 Alternate Electrolyte Evaluations
- 1.3 Performance Evaluations

3.1.1 Endurance Evaluation

In order to characterize the performance of any given cell, and thus accomplish the goals of this evaluation testing, a baseline configuration was established during Phase III utilizing the state of the art as of 1977. Table I contains a summary of the characteristics of the 1977 baseline cell configuration. Figures 8 and 9 contain performance data as demonstrated during testing under this task during Phase III.

By the end of Phase III, the results of this testing and other developmental efforts led to a reassessment of the configuration being analyzed. This reassessment resulted in the judgment that future performance and endurance analyses under Phase IV would be conducted on cells containing the then recently developed conductive wetproofing configuration. The factors pointing toward this approach included:

- The system demonstrated over 2000 hours of completely stable performance on scaled-up Unit NT-03. This dispelled many of the concerns over oxidation of the conductive wetproofing graphite structure at operating voltages.



Phase IV *



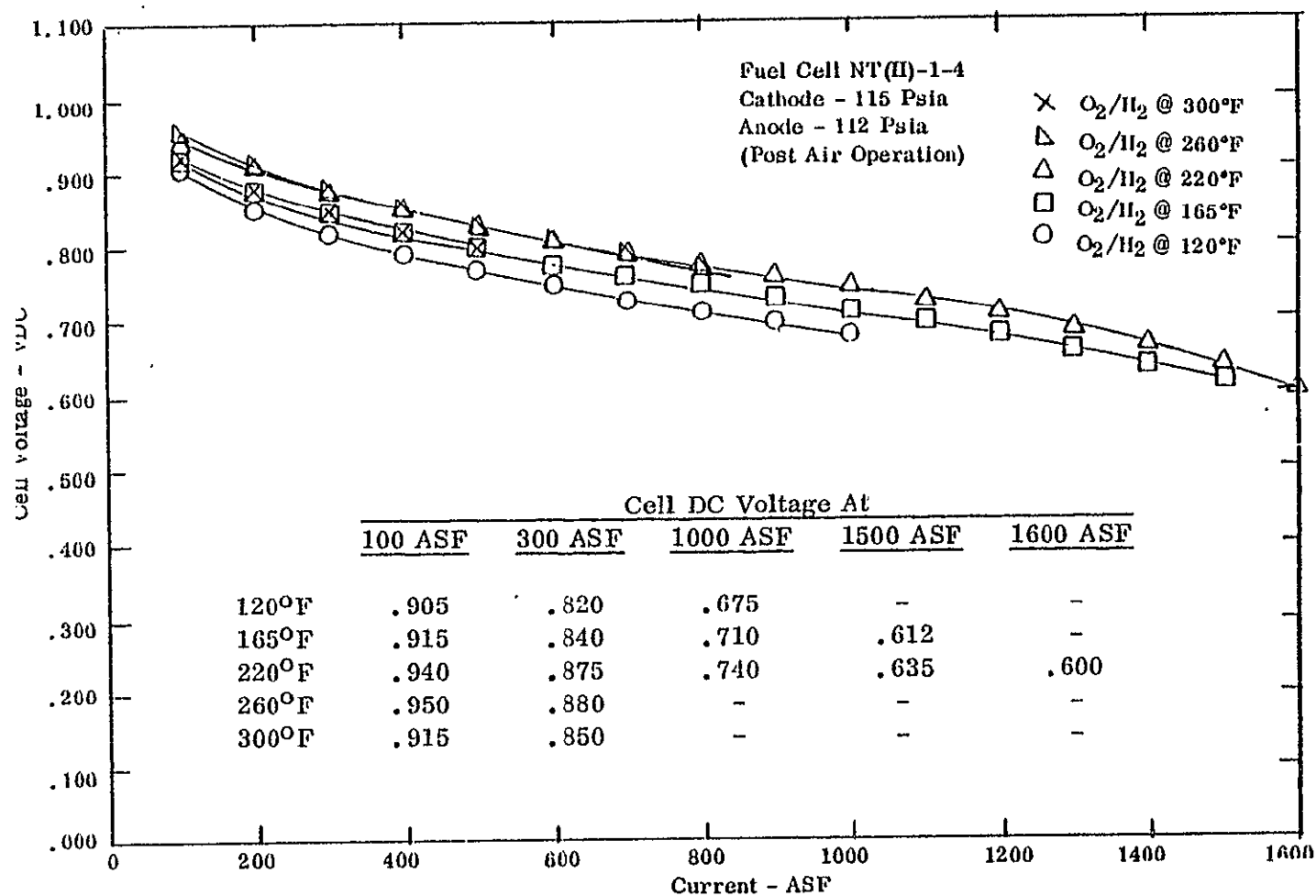
Figure 7. NASA/JSC Technology Program

TABLE I

A SUMMARY OF THE 1977 BASELINE CELL CONFIGURATION IS AS FOLLOWS:

- SOLID POLYMER ELECTROLYTE
 - DU PONT'S NAFION
 - 5 MILS THICK
 - 35-40% H₂O
 - 1200 EQUIVALENT WEIGHT
 - PLATINIZED
- ANODE
 - 4 GRAMS/FT² NOBLE METAL LOADING
 - 64% PT, 21% RU, 15% WO₂
 - 15% T-42 (TEFLON)
 - GOLD SCREEN (DISTRIBUTION) ASSEMBLY
- CATHODE
 - 4 GRAMS/FT² NOBLE METAL LOADING
 - 12.5% T-30 100% PT (TEFLON)
 - 1/4 INCH STAND PIPE
 - 3 MIL GOLD SCREEN
 - CHEMPLAST WETPROOFING (POROUS TEFLON)
- CURRENT COLLECTION
 - BIPOLAR
 - OPEN CATHODE GAP



Figure 8. O_2/H_2 - High Current Density Performance

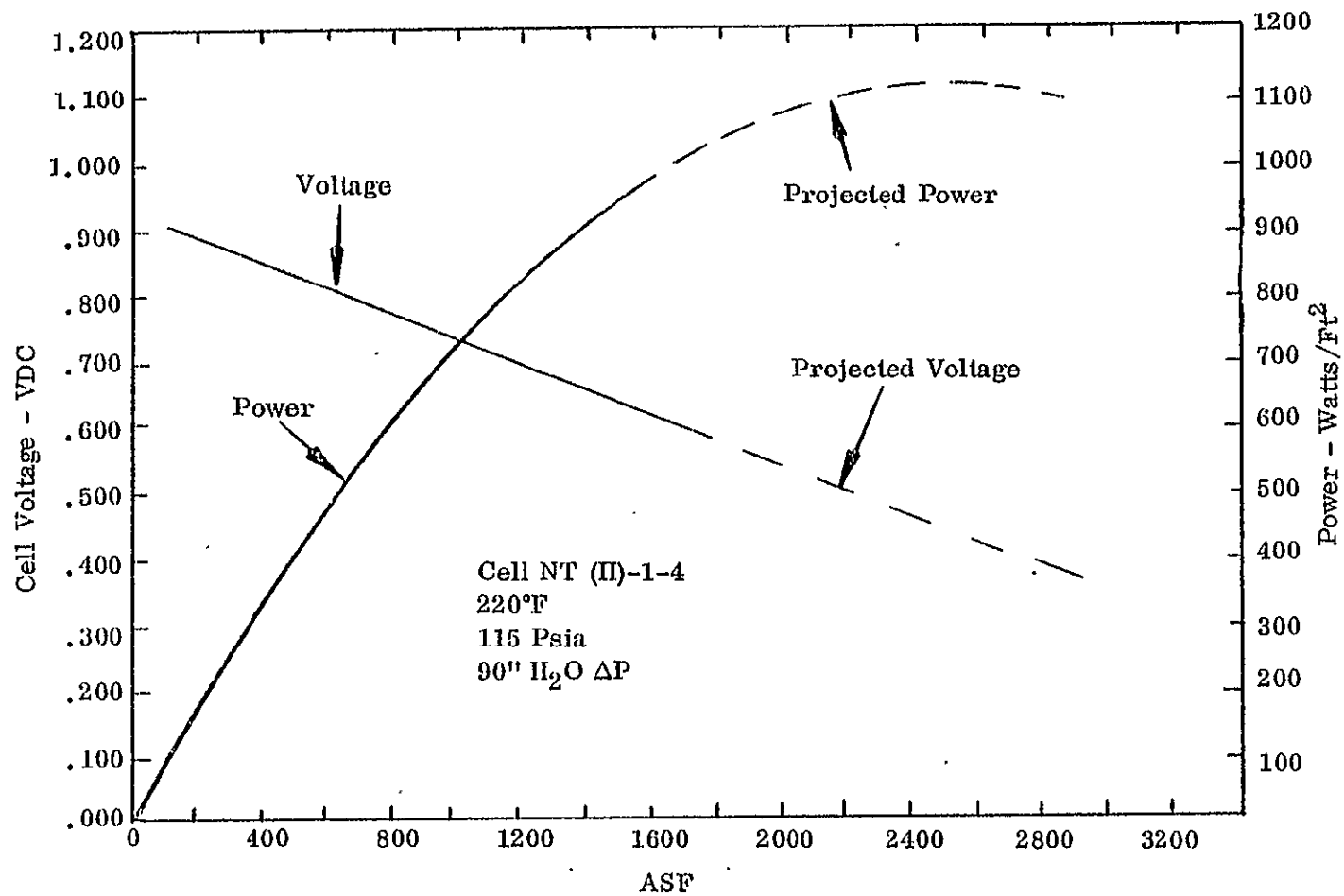


Figure 9. O₂/H₂ - Power vs. Voltage

- A conductive wetproofing was desirable for scaled-up hardware to minimize IR losses.
- Because the conductive wetproofing configuration provided full support to the electrolyte polymer on both sides, facility failures of the type involving oxygen loss would not damage the cells.
- Extrapolated performance from Cell NT-03, and from the 10-mil thick cells on the IR&D Program with conductive wetproofing, demonstrated an equivalent performance between the non-air activated baselines and the non-air activated conductive wetproofing configuration.
- Because the conductive wetproofing configuration eliminated the cathode current collection screen and its 2-3 mil penetration into the polymer, greater structural strength of the polymer resulted by increasing the minimum cross section from approximately 2 mils to 4 mils.

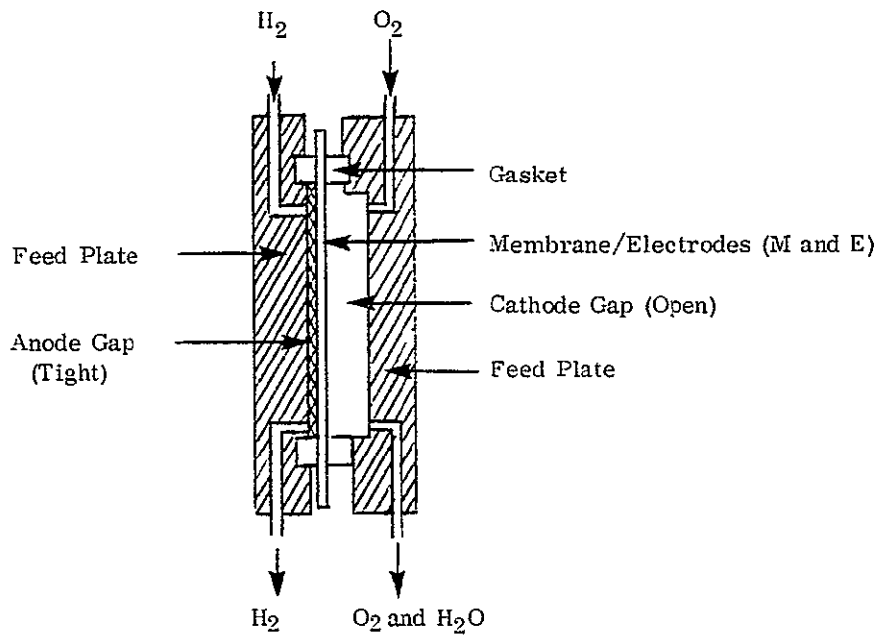
For the above reasons, it was decided to accelerate the conductive wetproofing effort as it continued into Phase IV, and to use cells so configured in the testing under Task 1.0. Figure 10 compares the configuration of the 1977 baseline 3" X 3" cell and hardware to the configuration of the 3" X 3" cell with conductive wetproofing, both as initially developed and as it existed at the end of Phase IV. The initial and present conductive wetproofing configurations are pictorially represented in Figures 11 and 12.

The introduction of the conductive wetproofing configuration into the 3" X 3" endurance test program did eliminate the problem of reversed pressure failures resulting from any one of several facility-type malfunctions. However, the endurance testing of the conductive wetproofing cells did exhibit several modes of performance loss and failure not observed in the non-conductive wetproofing configuration. The timing of these design deficiencies was fortunate, however, in that corrective action was able to be applied to the design of the 1.1 Ft² cell. The major deficiencies identified and corrective actions taken were as follows:

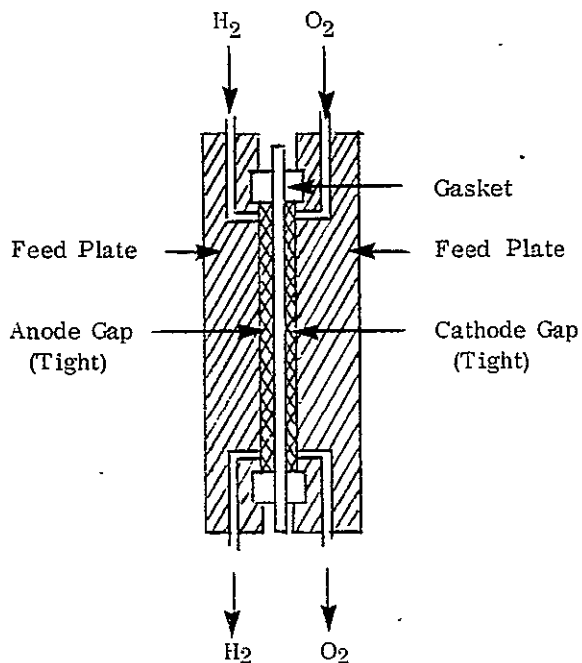
- The SPE tended to creep with time through the anode expanded metal flow field screen, eventually resulting in cuts in the SPE. The high compression pressure needed to obtain a perimeter seal and low cell resistance accelerated this creep process. Corrective actions included incorporation of an independent seal and active area compression configuration, and the introduction of an anode support plate of wetproofed graphite (ST-4).
- Product water flooding of the cell resulted in lower performance. In the previous non-conductive wetproofing configurations, water had been removed by wicks or by gravity. Corrective action included increasing through-cell flow rates of oxygen reactant and redesign of flow fields.



Configuration of 1977 Baseline (3 x 3 Hardware)



Configuration of Initial Conductive Wetproofing



Configuration of Present Conductive Wetproofing

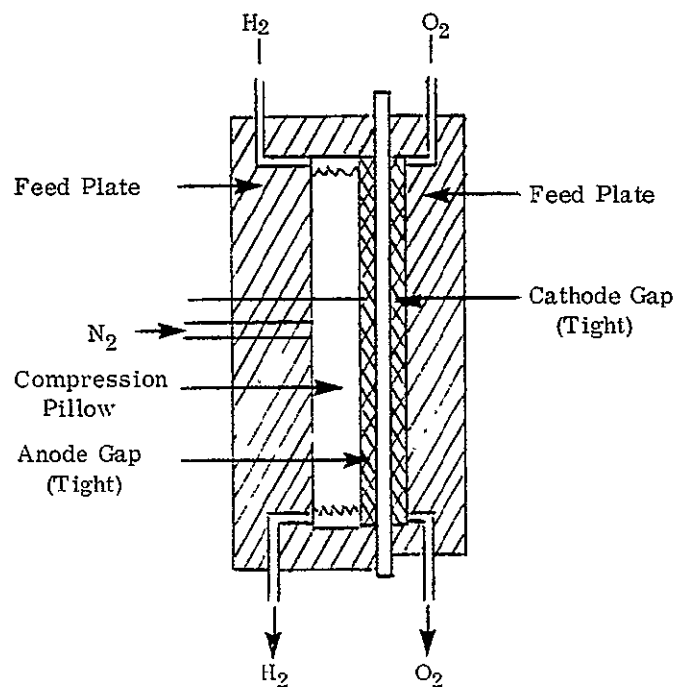


Figure 10. Comparison of Configurations: Baseline vs. Initial and Follow-On

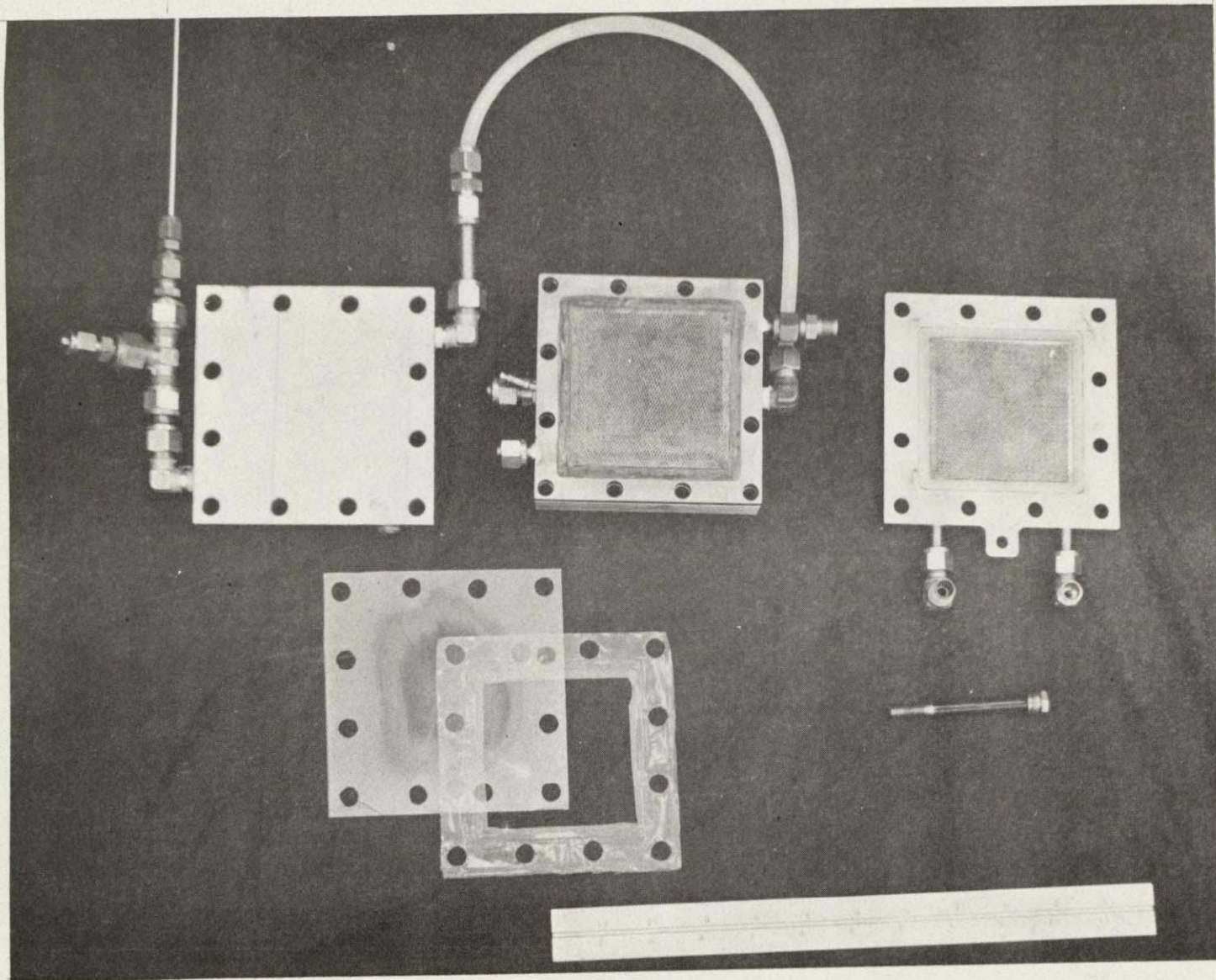


Figure 11. Initial Conductive Wetproofing Configuration

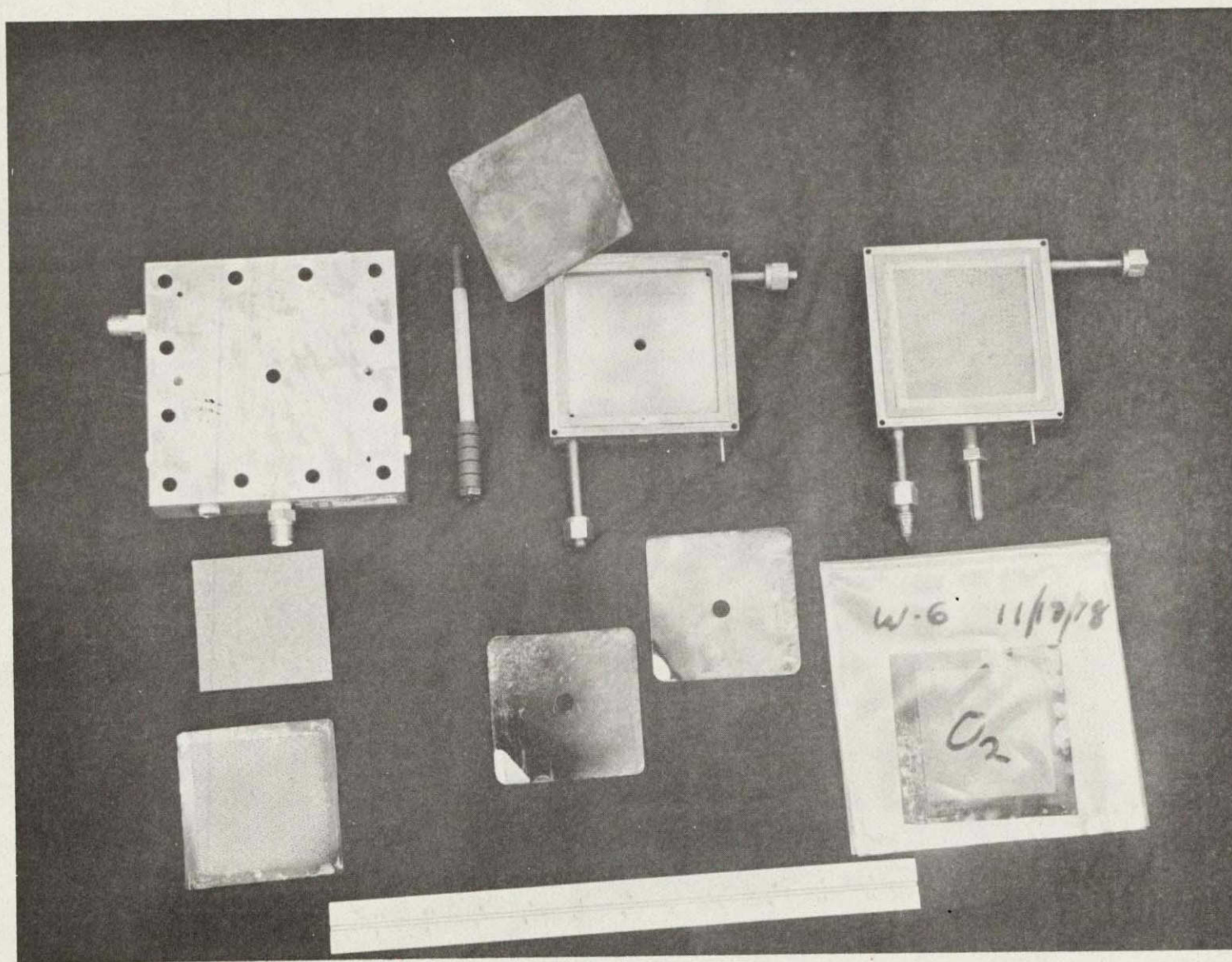


Figure 12. Present Conductive Wetproofing Configuration

the membrane will result in only minimal impact on the cost of the unit itself. The most important factor in this particular application is performance; the further development of RAI membrane performance characteristics would require a considerable expenditure of time and money, totally negating the effects of its initially cheaper cost.

Even for application to large-scale production of fuel cells, RAI membrane no longer represents the advantage thought to exist at the beginning of these investigations. The cost projections of this membrane show an increase with time, while the cost of Nafion has been steadily decreasing, as the following table demonstrates:

TABLE II

	<u>Nafion Cost</u>	<u>1978 Dollars</u>
• 1967	\$150/Ft ²	\$300/Ft ²
• 1972	\$35/Ft ²	\$50/Ft ²
• 1978	\$30/Ft ²	\$30/Ft ²
• 1983 (Projected)	\$22/Ft ²	\$15/Ft ²

In addition, the results of the evaluation of the modified Nafion showed it to represent no real improvement in the fuel cell application over Nafion as currently used, and thus this membrane was also deleted from continued investigative efforts under this task in Phase IV. Hereafter, resources designated for this task were applied to more fruitful areas, such as endurance testing.

3.1.3 Performance Evaluations

Commenced under Phase III, the purpose of this sub-task was to gain insight into the performance improvement of Cell NT(II)-1-4 observed following H₂/air operation, when returning to H₂/O₂ operation. As a result of the Phase III effort, a post-air performance improvement mechanism was postulated and partially demonstrated in operational testing (Cell NT(III)-1.5-1). At approximately the same time, improvements in the performance of cells configured with conductive wetproofing established levels of performance equivalent to the pre-air operation of Cell NT(II)-1-4. (See performance of Cell W-3 on Figure 13.) With the beginning of Phase IV, the decision was made to redirect further performance evaluations to the conductive wetproofing configuration of cells such as NT-03(.7 Ft² cell). As this phase progressed, the emphasis became primarily focused on endurance rather than performance evaluations, due to the initially poor results of the endurance testing.

3.1.4 NT-03 (.7 Ft² Development Cell) Performance

The purpose of this sub-task was to demonstrate that the advances made in 3 X 3 laboratory-sized cells and hardware could be scaled-up and



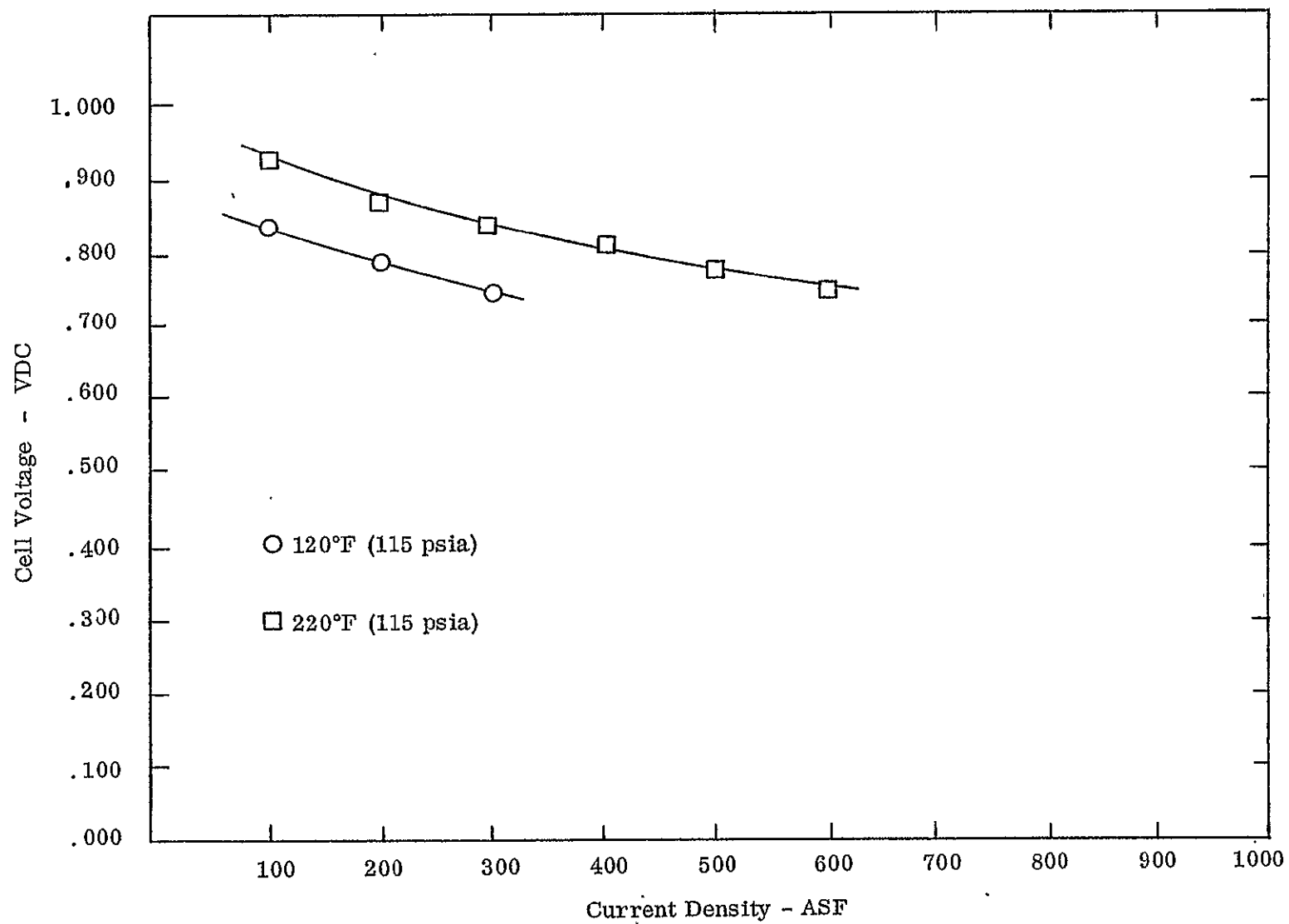


Figure 13. Performance Data, Cell W-3 (Conductive Wetproofing)



applied to larger cells. The size of .7 Ft² was established early in the program as a likely intermediary between the 3 X 3 cells and full operational size.

NT-03 began load operation on October 4, 1977, during effort under Phase III. This cell incorporated new design features generated as a result of the GE/DECP IR&D effort on conductive wetproofing. These modifications to the earlier NT-02 design included:

- Corrugated titanium coolant system trusses to replace the polypropylene screens.
- Conductive wetproofing to replace the interrupted Teflon wetproofing.
- Frame porting to replace port trusses for improved stack up.
- 10-mil thick Nafion electrolyte reduced to 5-mil.

Figure 14 shows a cross-section of the new stack.

By the end of Phase III, Cell NT-03 had accumulated 3,388 hours of extremely stable performance at 16 psia and 165°F. Testing of this cell continued into Phase IV, operating for a total of 5,819 hours before a facility power loss resulted in a shutdown and normal oxygen takeover. Figure 15 displays cell NT-03 performance levels during the test. The HF release rate had remained in the 50 - 150 PPB range throughout.

During checkout prior to reactivation, both excessive cross-electrolyte and overboard oxygen leakage were observed. Teardown analysis revealed two factors which related to the leakage conditions:

- The Teflon double-sided adhesive frames had undergone some creep with operational time, and the stack compression load in the perimeter seal area was considerably reduced.
- An original time zero screen puncture which had been successfully patched with Teflon and silicone adhesive before initial activation was found to leak at teardown. This original screen puncture resulted from misalignment of the oxygen flow distribution screen package.

The overboard leakage was undoubtedly the result of the loss of seal area compression, whereas the cross-electrolyte leakage could have arisen from either of two probable causes:

- With decreased seal area compression, cross-manifold O₂-to-H₂ leakage could have occurred.
- The original puncture could have opened during the flexing of the electrolyte as the automatic oxygen takeover shutdown proceeded.



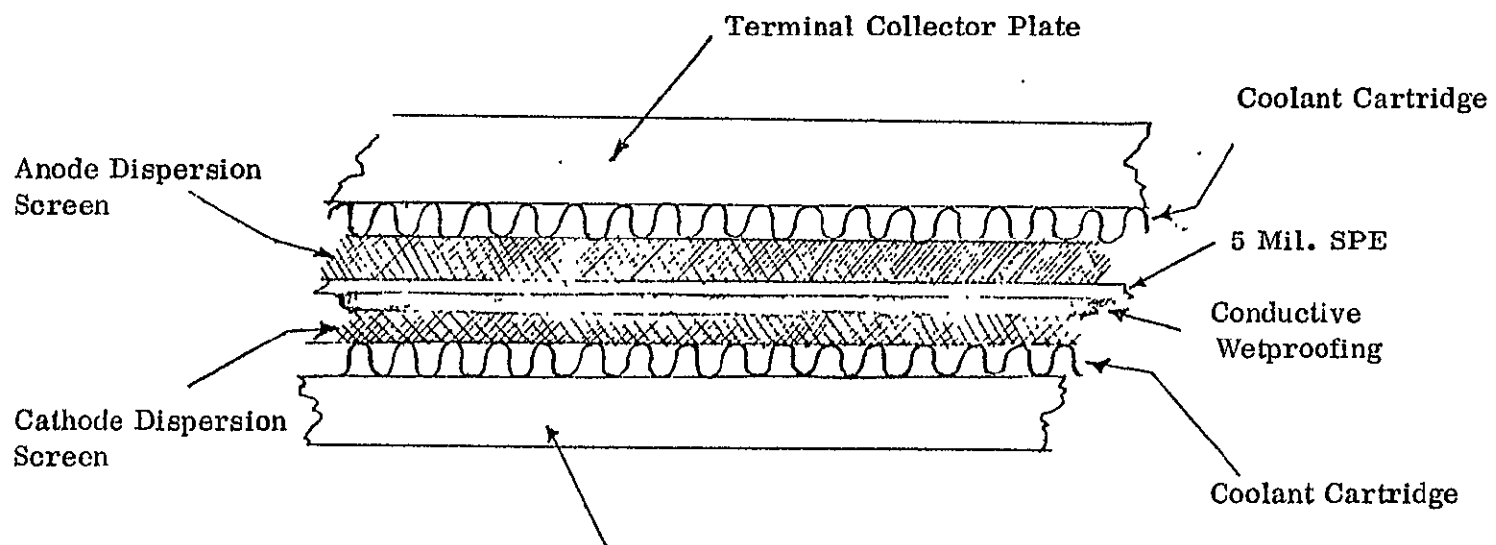
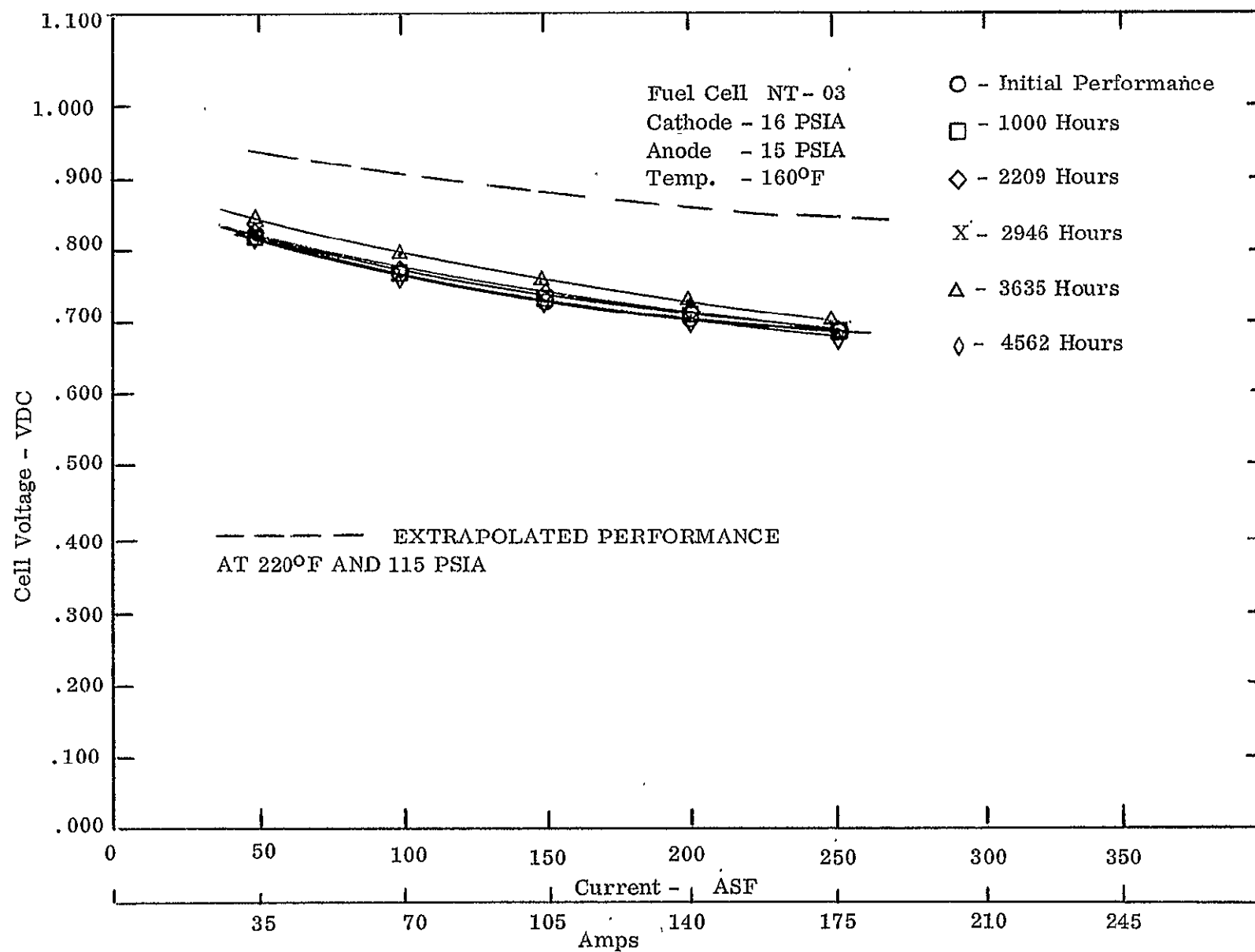


Figure 14. NT-03 Cross Section



Figure 15 - O₂/H₂ Performance

The electrolyte damage which occurred as a result of the facility power failure was repaired with Teflon and silicone adhesive, and the unit was reassembled with tie rod springs. Following installation of the unit into the test facility, a series of leakage, flow and electrical checkout tests indicated that all was normal.

The unit was activated, and performance appeared normal at room temperature. As the operational temperature of the unit was increased, the normal performance improvement was noted. After approximately nine hours of operation in an unattended mode, a slow performance decrease developed. This decay continued over a two-hour period until a low voltage shutdown resulted.

A post-test leakage check indicated that a cross-electrolyte leakage had redeveloped. A teardown, analysis and repair procedure was not initiated as manpower was committed to the fabrication of the 1.1 Ft² single cell unit. Since it was strongly suspected that the leakage development is the result of the loosening of an electrolyte patch, it was doubtful that a teardown analysis would have contributed to redirection of the 1.1 Ft² hardware fabrication. As of the end of Phase IV, manpower remained committed to the 1.1 Ft² cell activity. Testing and evaluation will continue in Phase V to identify long-term failure mechanisms.

3.2 Task 2.0 - Regenerative Fuel Cell Testing and Evaluation

The study of a Hydrogen/Oxygen Regenerative Fuel Cell was conducted under Task 2.0 to determine the feasibility of using a single unit that would combine the functions of a fuel cell and an electrolysis unit for space applications. The regenerative unit would reduce the system weight considerably and is a likely prospect, assuming that the performance is not affected adversely.

The regenerative fuel cell operates both in the fuel cell and electrolysis modes. During fuel cell operation, the system derives electrical energy from the conversion of the gaseous reactants, hydrogen and oxygen, into water. The water produced by the fuel cell reaction is pumped into an electrolysis chamber, where the passage of an electrical current reconverts it to the gaseous state. Product gases are then held in high pressure storage until needed by the fuel cell. Electrical energy for operation of the electrolysis cell is obtained from a solar array, which is the ultimate source of all power.

The electrical power is generated during the daylight hours using the solar array. During this period hydrogen and oxygen are produced. These reactants are combined to generate electrical power during the dark-side operation.

Although the idea of a regenerative fuel cell results in considerable reduction of system weight, the study primarily considered the advantages and disadvantages of such a system by operating under various electrode configurations. Tests were conducted to determine the performances of:



- (1) E-5 Anode, E-5 cathode with conductive wetproofing
- (2) Pt Anode, E-50 cathode with conductive wetproofing
- (3) Pt Anode, Pt cathode with conductive wetproofing.

The performance of a hydrogen/oxygen regenerative fuel cell was also compared in this effort with hydrogen/halogen regenerative fuel cells in an effort to identify the available options. Figure 16 shows the performance of the best O₂/H₂ Regenerative Fuel Cell at ambient temperature compared to two demonstrated hydrogen/halogen cycles. Figure 17 displays the same O₂/H₂ Regenerative Cell operating at 220°F in comparison to projected performance of the hydrogen/halogen cycles at 194°F.

A detailed description and analysis of the effort conducted under the task can be found in a separate report, "Final Test and Evaluation Report Covering Regenerative Fuel Cells (H₂O), (HCl) and (HBr)", dated May 26, 1978, and published in fulfillment of DRL Line Item No. 2, NASA Contract No. NAS9-15286. A summary of the results obtained during this study can be seen in Table III (Comparison of State-of-the-Art System Weights), Table IV (Comparison of System Costs), and Table V (Advantages versus Disadvantages of Each System).

As a consequence of these results, the following conclusions were drawn:

A comparison study of the H₂O, HCl and HBr regenerative cycles indicates that the HCl cycle has both the lowest weight and cost for the particular set of assumptions. The H₂O cycle has the major advantages of being much further along in development and can be integrated with environmental control systems. The hydrogen/halogen cycles may be utilized with advantage if energy storage and in-space chemical process materials are integrated, or if pure energy storage is desired.

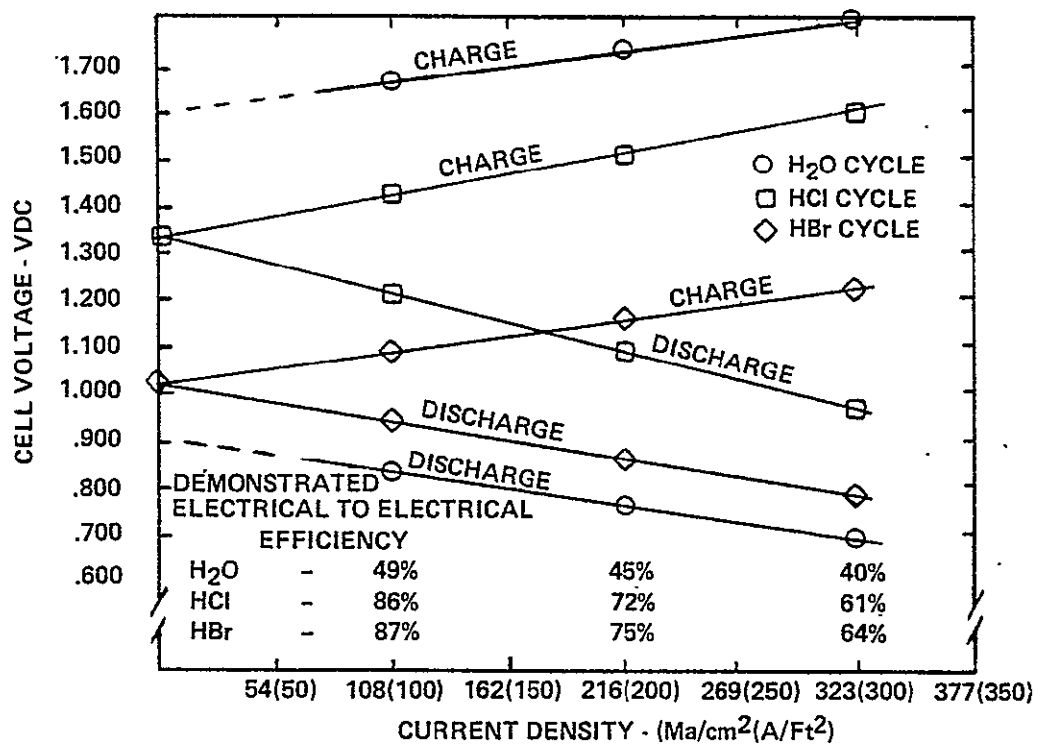
At this point in time it would therefore appear that each of the cycles has potential for space application.

It is anticipated that, with the advancement of fuel cell technology and solar energy systems, the weights and costs of the regenerative cycles will be reduced considerably. Projections are shown in Tables VI and VII.

3.3 Task 3.0: Stack Design

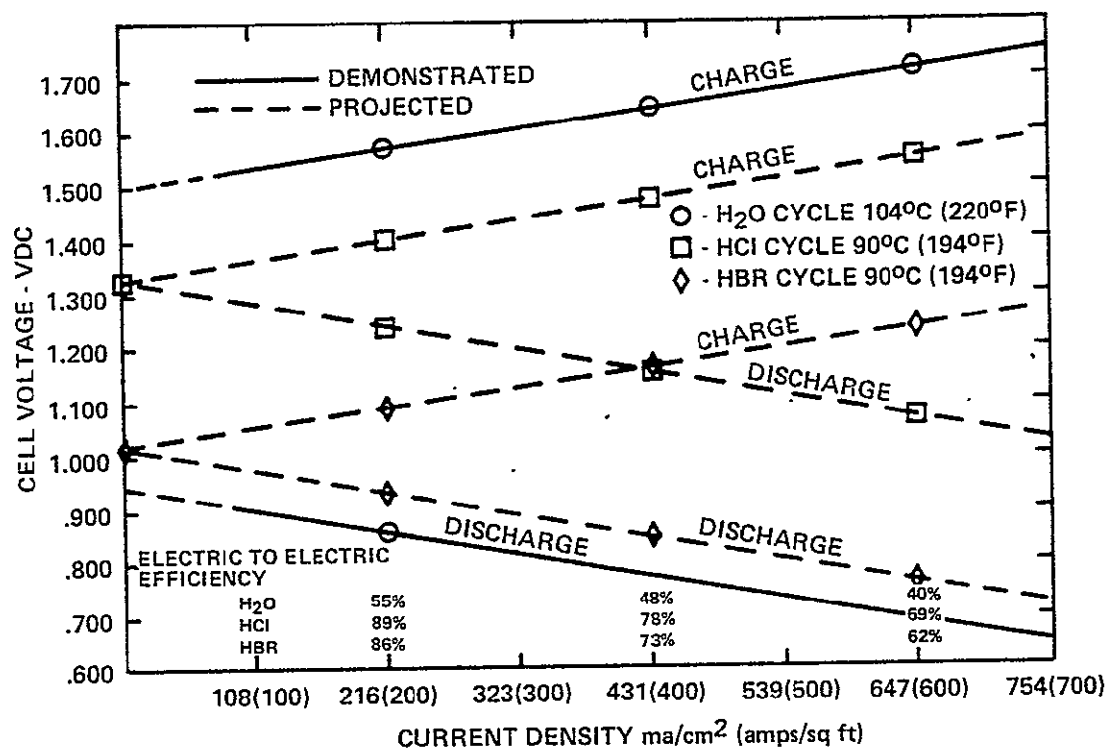
The overall purpose of this task was to design a single fuel cell and its support equipment which could be used in several different space applications. The design was based on the results of a system study conducted primarily during Phase III which examined various applications submitted by NASA/JSC. (Specifically, power systems for a space station, space tug, power platform, and second-generation space shuttle) The task was divided into two sub-tasks: 3.1, "Bench Testing", concerning bench-testing of configuration concepts, and 3.2, "Final Design", comprising the design of this cell and support equipment such as the rods and end plates.





Demonstrated Ambient Temperature SPE Regenerative Cycles

Figure 16.



Demonstrated and Projected SPE Regenerative Cycles

Figure 17.

TABLE III
COMPARISON OF CURRENT SYSTEM WEIGHTS *
FOR THE H₂O, HCl AND HBr CYCLES

COMPONENT	H ₂ O Cycle System Wt. (lbs)	HCl Cycle System Wt. (lbs)	HBr Cycle System Wt. (lbs)
Regenerative Fuel Cell Unit @ 15 lbs/KW	375 (750)	375	375
Solar Array @ 14 lbs/KW	750	570	590
Reactant Storage	15	40	40
Reactants	15	105	240
Power Conditioning @ 5 lbs/KW	125	125	125
Cabling @ 3 lbs/KW	75	75	75
Heat Rejection	100	45	50
TOTAL CURRENT WEIGHT	1455 lbs (1830 lbs)	1335 lbs	1495 lbs

() The terms in parentheses are the weights for 2 identical fuel cell units. As the reversal from the electrolysis mode to the fuel cell mode is not instantaneous for the H₂O cycle, it may be necessary to use 2 units - one for electrolysis operation and the other for fuel cell operation.

* Assumptions include:
25 KW Constant Load
90 Minute Orbit
30 Minute Dark Side Operation



TABLE IV
COMPARISON OF CURRENT SYSTEM COSTS **
FOR THE H₂O, HCl AND HBr CYCLES

COMPONENT	H ₂ O Cycle System Cost (in \$K)	HCl Cycle System Cost (in \$K)	HBr Cycle System Cost (in \$K)
Regenerative Fuel Cell Unit @ \$15K/KW	375 (750)	375	375
Solar Array @ \$15K/KW	805	610	635
Reactant Storage	5	10	10
Reactants *	-	-	-
Power Conditioning @ \$5K/KW	125	125	125
Cabling @ \$1K/KW	25	25	25
Heat Rejection	125	55	60
TOTAL CURRENT COSTS	\$1,460K (\$1,835)	\$1,200K	\$1,230K

() The terms in parentheses are the cost for 2 identical fuel cell units. As the reversal from the electrolysis mode to the fuel cell mode is not instantaneous for the H₂O cycle, it may be necessary to use 2 units - one for electrolysis operation and the other for fuel cell operation.

* Reactant costs are negligible compared to the other costs.

** Assumptions Include: 25 KW Constant Load
90 Minute Orbit
30 Minute Dark Side Operation



TABLE V
ADVANTAGES/DISADVANTAGES

ADVANTAGES

DISADVANTAGES

H₂O CYCLE

- Flexible Reactants
- Non-Corrosive Fluids
- Demonstrated Life

- High Heat Rejection
- Reversal From Electrolysis To Fuel Cell Mode Not Instantaneous - May Require Two Separate Electrochemical Units
- Low Conversion Efficiency

HCl CYCLE

- Very High Conversion Efficiency
- Low Heat Rejection
- Low Noble Metals
- Single Electrochemical Unit
- Instantaneous Reversal of Fuel Cell and Electrolysis Operations

- Corrosive Fluids
- Toxic Fluids
- High Reactant Weight
- High Pressures For Liquefaction of Chlorine
- Performance Level Change With Acid Concentration

HBR CYCLE

- High Conversion Efficiency
- Low Heat Rejection
- Low Pressure
- State-Of-The-Art Materials
- Low Noble Metals
- Single Electrochemical Unit
- Instantaneous Reversal of Fuel Cell and Electrolysis Operation

- Corrosive Fluids
- Toxic Fluids
- Very High Reactant Weight
- Performance Level Change With Acid Concentration



TABLE VI
COMPARISON OF FUTURE SYSTEM WEIGHTS *
FOR THE H₂O, HCl AND HBr CYCLES

COMPONENT	H ₂ O Cycle Future System Wt. (lbs)	HCl Cycle Future System Wt. (lbs)	HBr Cycle Future System Wt. (lbs)
Regenerative Fuel Cell Unit @ 9 lbs/KW	225 (450)	225	225
Solar Array @ 8 lbs/KW	430	325	335
Reactant Storage	15	40	40
Reactants	15	105	240
Power Conditioning @ 5 lbs/KW	125	125	125
Cabling @ 3 lbs/KW	75	75	75
Heat Rejection	100	45	50
TOTAL FUTURE WEIGHT	985 lbs. (1210 lbs)	940 lbs.	1090 lbs

() The terms in parentheses are the cost for 2 identical fuel cell units. As the reversal from the electrolysis mode to the fuel cell mode is not instantaneous for the H₂O cycle, it may be necessary to use 2 units - one for electrolysis operation and the other for fuel cell operation.

* Assumptions include: 25 KW Constant Load
90 Minute Orbit
30 Minute Dark Side Operation



TABLE VII
COMPARISON OF FUTURE SYSTEM COSTS**
FOR THE H₂O, HCl AND HBr CYCLES

COMPONENT	H ₂ O Cycle Future System Cost (in \$K)	HCl Cycle Future System Cost (in \$K)	HBr Cycle Future System Cost (in \$K)
Regenerative Fuel Cell Unit @ \$7K/KW	175 (350)	175	175
Solar Array @ \$10K/KW	535	405	425
Reactant Storage	5	10	10
Reactants*	—	—	—
Power Conditioning @ \$5K/KW	125	125	125
Cabling @ \$1K/KW	25	25	25
Heat Rejection	125	55	60
TOTAL FUTURE COST	\$990K (\$1,165K)	\$795K	\$820K

() The terms in parentheses are the cost for 2 identical fuel cell units. As the reversal from the electrolysis mode to the fuel cell mode is not instantaneous for the H₂O cycle, it may be necessary to use 2 units - one for electrolysis operation and the other for fuel cell operation.

* Reactant costs are negligible compared to other costs.

** Assumptions Include:

25 KW Constant Load
90 Minute Orbit
30 Minute Dark Side Operation



The system study outputs had established a cell sizing of 1.1 Ft² as near optimum for the space applications of interest. Detailed design and testing efforts began in Phase IV. Upon completion of the initial bench testing of flow field components, the coolant flow field was initially designed as a diamond pattern with a .035 inch draw for the 1.1 Ft² cell, the diamonds being approximately 0.35 inch by 0.45 inch. Flow distribution was very uniform at one liter per minute with three-channel flow. Inlet-to-outlet differential pressure (including porting) was in the range of 2-3 psi at room temperature.

The two-phase flow of the cathode chamber was configured around a 2/0 screen forming of niobium foil. The depth of flow field draw was established as approximately 0.010 inch. The flow characteristics were evaluated with flow rates up to 500 cc/min, and pressure differentials up to 15 inches of water.

Samples of the sheetmetal configurations selected as a result of the flow tests were compression-tested at 175 psi (the maximum desired end plate loading). Excessive deflection resulted when the three separator sheets were constructed of 5-mil thick niobium. Acceptable deflection resulted when the coolant flow distribution sheet was fabricated from 5-mil thick titanium.

An alternate coolant flow distribution configuration utilizing a "pin" field in place of the "screen" field was later evaluated. This configuration was shown to provide compression qualities superior to those of the expanded screen pattern. Flow tests showed somewhat larger pressure drops, but which still remained within an acceptable range. The "pin" field was selected for the design fabrication based on these compression results.

Non-flight type end plates were also designed as a part of this task. The fluid porting end plate was designed as a ridged component simulating the stack midplate of a multiple-KW stack. The compression end plate was designed to have a pneumatic diaphragm with an elastomeric seal to provide stack compression loads.

Certain aspects of the design of the 1.1 Ft² cell are considered to be particularly valuable in preventing/avoiding difficulties encountered with Cell NT-03. Specific problems addressed by this new design include the following:

- Stack/frame creep is greatly reduced by the use of niobium frames. The only material in the frame area that may creep under operating conditions is the electrolyte membrane itself.
- Stack creep is compensated for by the dynamic, pneumatically actuated compression diaphragm.
- The 1.1 Ft² cell design eliminates all expanded screen components, along with their potential capability of causing puncture damage.



3.4 Task 4.0 - Single Cell Evaluation

This task was also divided into two sub-tasks: Sub-Task 4.1, "Single Cell Fabrication", and Sub-Task 4.2, "Single Cell Facility Preparation and Test". The major design and projection operational characteristics of the 1.1 Ft² scaled-up hardware are displayed in Table VIII.

Long-lead items for the fabrication of the single cell and test facility were ordered early in Phase IV, the test facility being completed essentially on time. However, delays were experienced in obtaining one critical item for fabrication of the single cell, namely niobium foil to be used in forming the reactant flow fields. This vendor delay, due to a rolling mill failure, caused an initial slippage of six weeks in the schedule. Delays were subsequently experienced in the forming of flow field components.

Initial trial formings of the niobium and titanium foil flow field components produced cracked parts. It was necessary to break sharp edges and hand-finish the molds to yield the proper results. Once the flow field molds were perfected, foil surface defects which did appear were checked with a penetrant inspection method.

Electron beam welding trials of the flow field components produced good results after several procedural modifications. Leak checks of the finished assemblies were performed with a procedure involving helium: Helium gas was directed at the seal area around the evacuated flow field assembly; a mass spectrometer sensed any helium which entered the flow field assembly area. The various components making up the completed 1.1 Ft² cell are displayed in Figures 18 through 25.

The single cell stack was assembled and pressure checks performed at 115 psig. During the 115 psig, preoperational pressure check of the completed stack, only minor weld leaks were detected in one of the formed foil separator sheets. At 75 psig on the pressure pad, the 1000 Hz, 50 amp resistance was .00026 ohms, a resistance level equivalent to that of the best 3 X 3 cells exhibited to date. Proof pressure testing of the end domes also took place with successful results to 263 psi (1.5 times maximum operating pressure).

After weld repair and after passing all preoperational checks, Fuel Cell stack No. 001 was activated. At 15 psig O₂, 11 psig H₂ and 120°F, Cell No. 001 achieved a 100 ASF voltage of .814 volts. Figure 26 shows the stack on the test facility. Operation at higher current densities was unstable due to limited product water removal. After 11 hours of operation, a short developed which required a system shutdown. The short originated in the area of two opposing weld irregularities in the alignment holes of the separator sheets. (These alignment holes were originally intended to align the stack during assembly, but have since been eliminated from further collector plate designs to enhance sealing and decrease cost.) The irregularities (less than .003 mil each) mated up and electrically shorted the cell after penetrating the membrane. The irregularities were removed and the separator sheets thoroughly inspected. No additional protrusions were discovered.



TABLE VIII
SCALE-UP CELL CHARACTERISTICS

• Weight (less coolant)	- 1.24 lbs. actual
• Thickness (cell spacing)	- 0.085"
• Cell Outside Dimensions	- 14" x 14"
• Cell Active Area	- 1.1 Ft ²
• Estimated Cell Coolant Weight	- 0.4 lbs.
• Operating Pressures	
Cathode	- 115 psia
Anode	- 111 psia
Coolant	- 115 psia
• Coolant Inlet Temperature	- 180°F
• Maximum Current Density	- 461 ASF
• Cell Voltage at Maximum ASF	- .777 VDC
• Maximum Cathode ΔP	- 15" H ₂ O
• Maximum Cathode Flow	- 6 SL/M
• Coolant Flow	- 1 L/M
• Ambient Internal Resistances	- 0.00028 Ohm
• Estimated Resistance @ Temperature	- 0.000175 Ohm



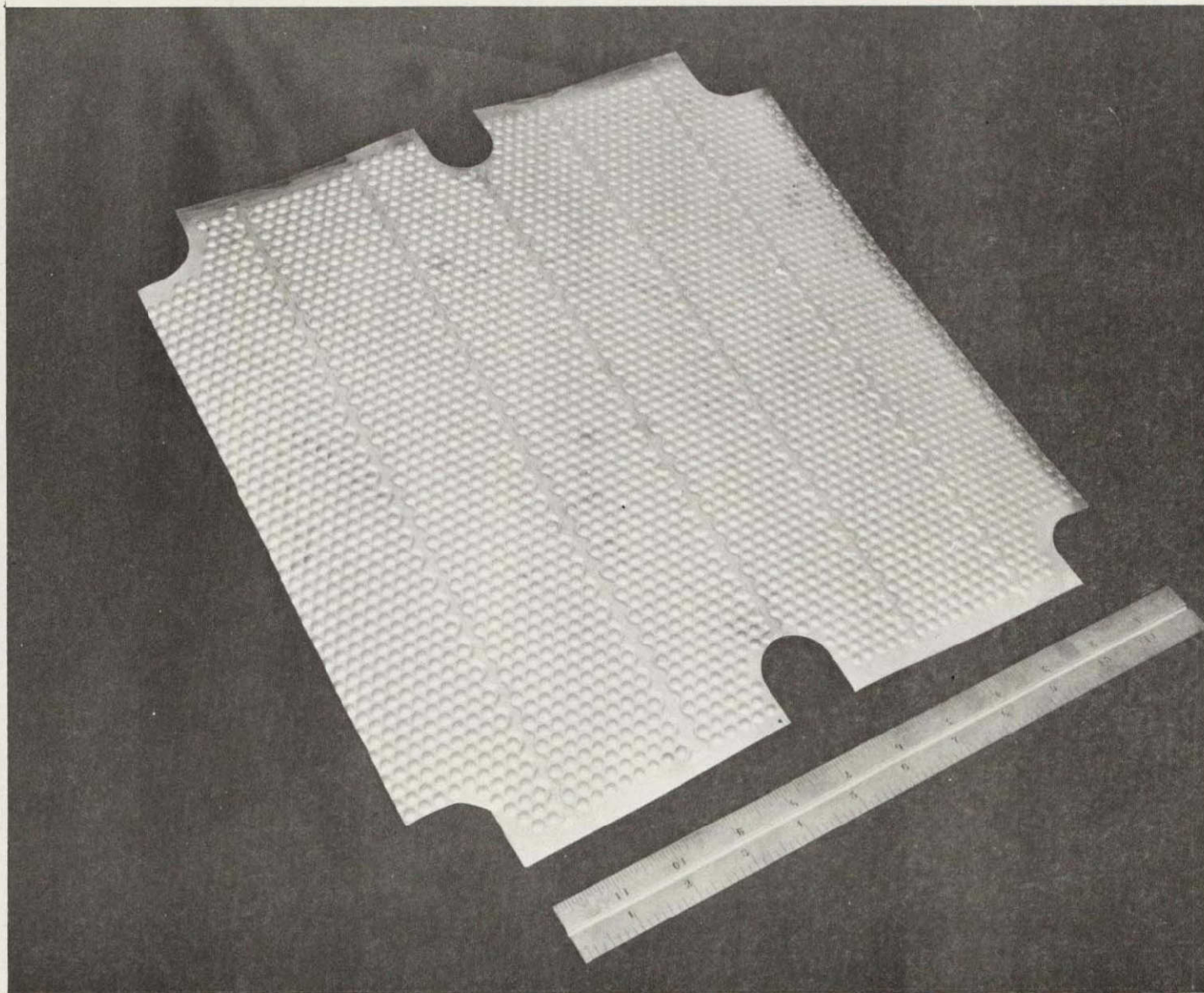


Figure 18. NASA 1.1 Ft² Cell Coolant Insert
(Coolant Flow Field)





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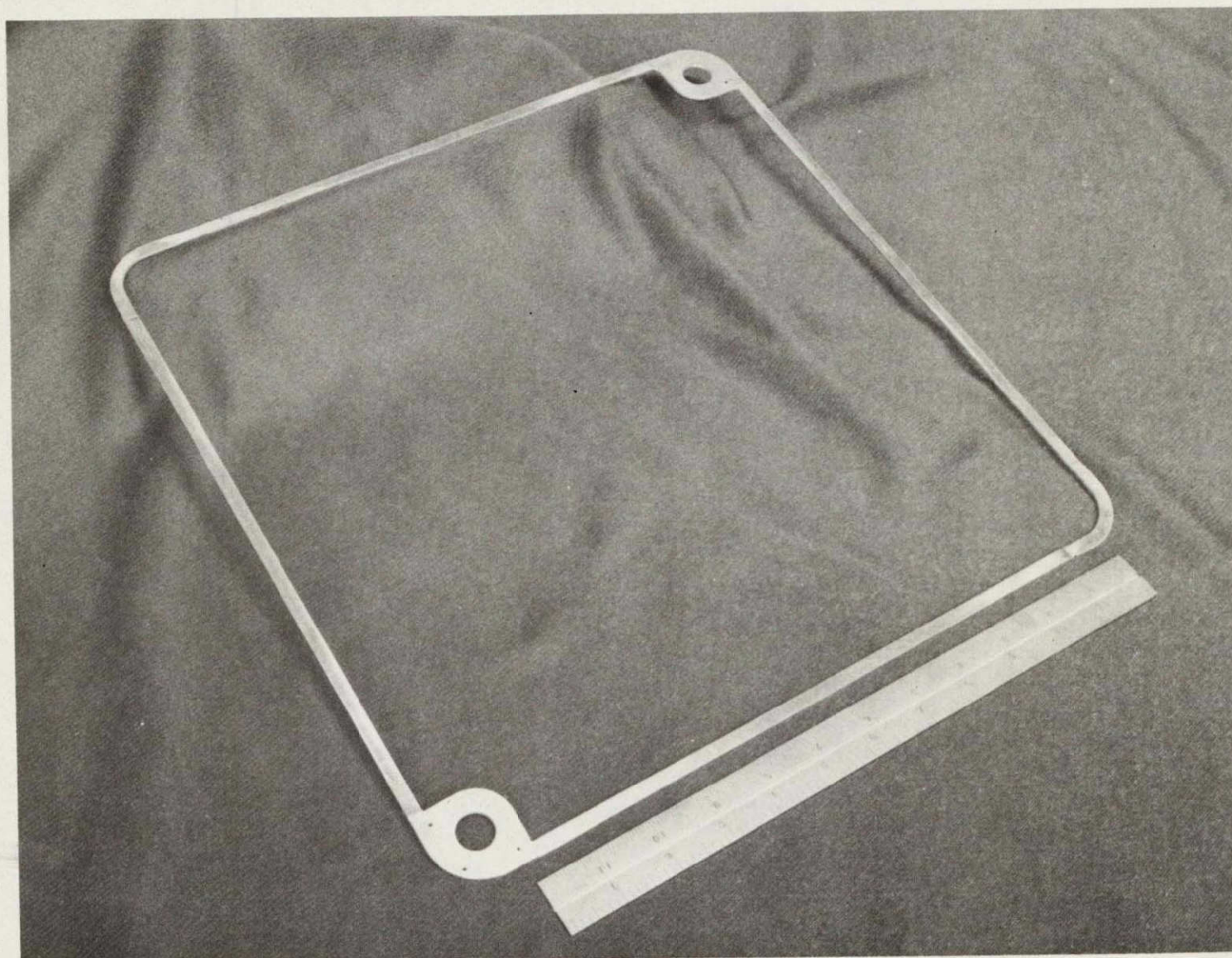


Figure 19. Welded Coolant Cartridge Frame for 1.1 Ft² Cell

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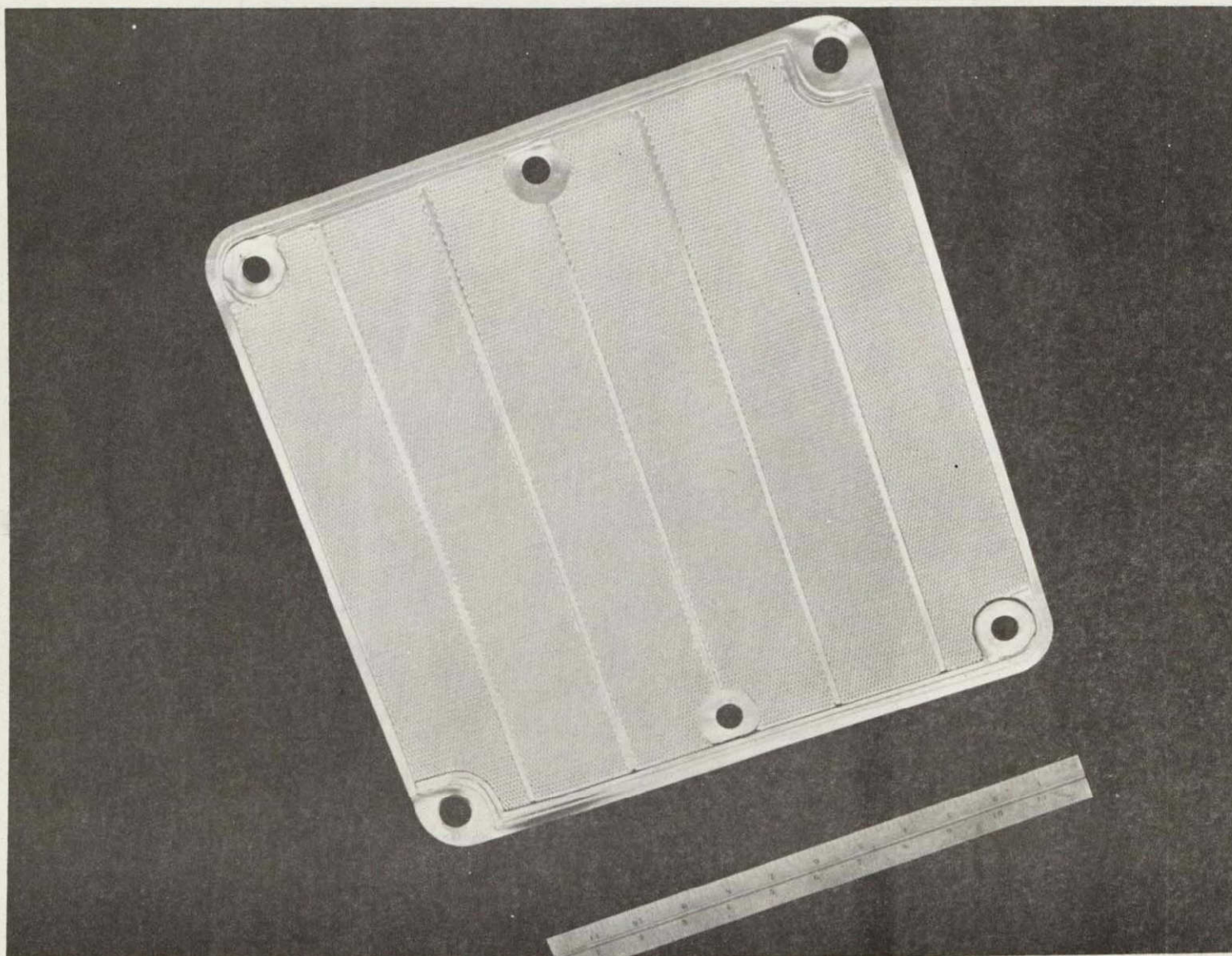


Figure 20. Cathode Flow Field for 1.1 Ft² Cell

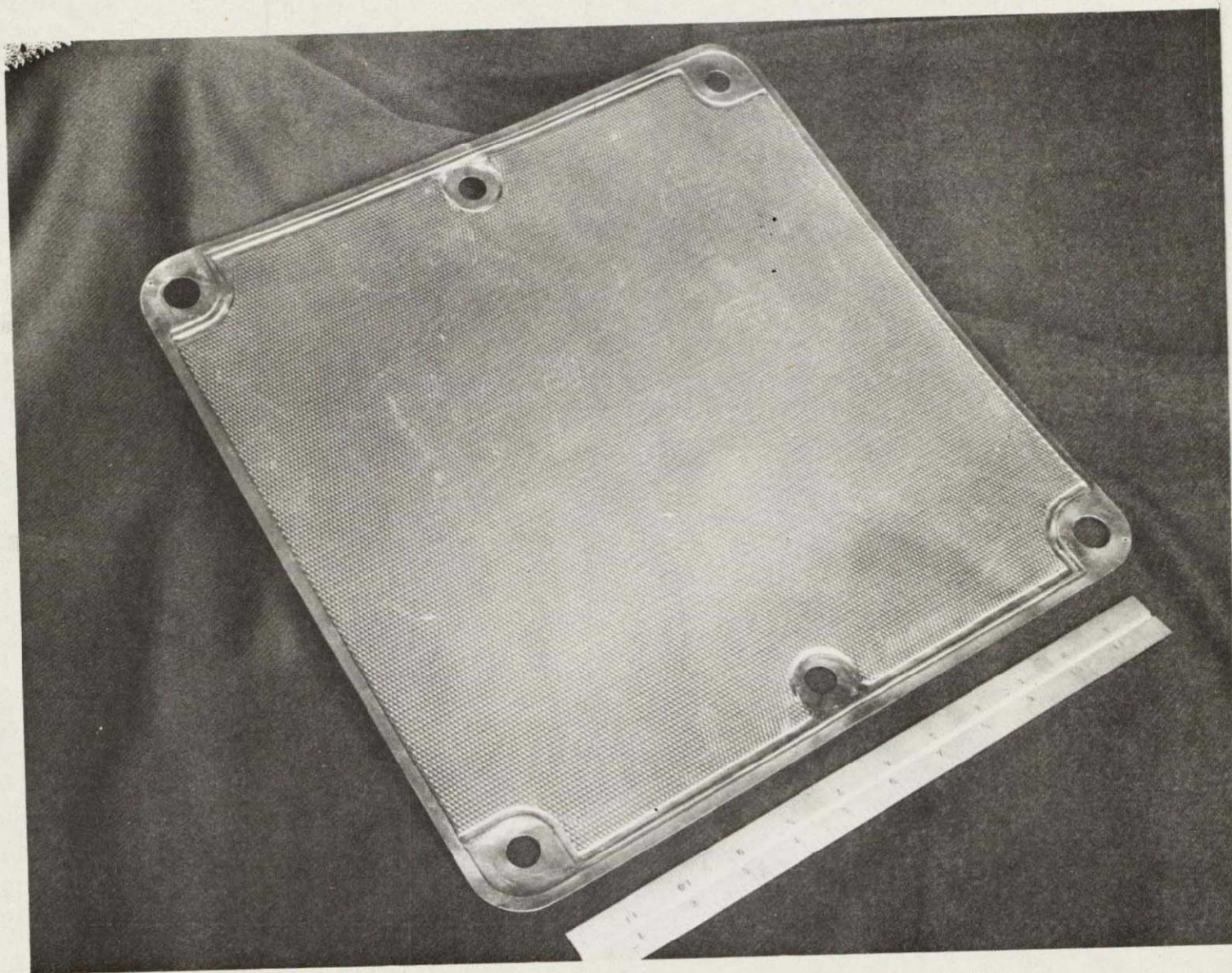


Figure 21. Anode Flow Field for 1.1 Ft² Cell



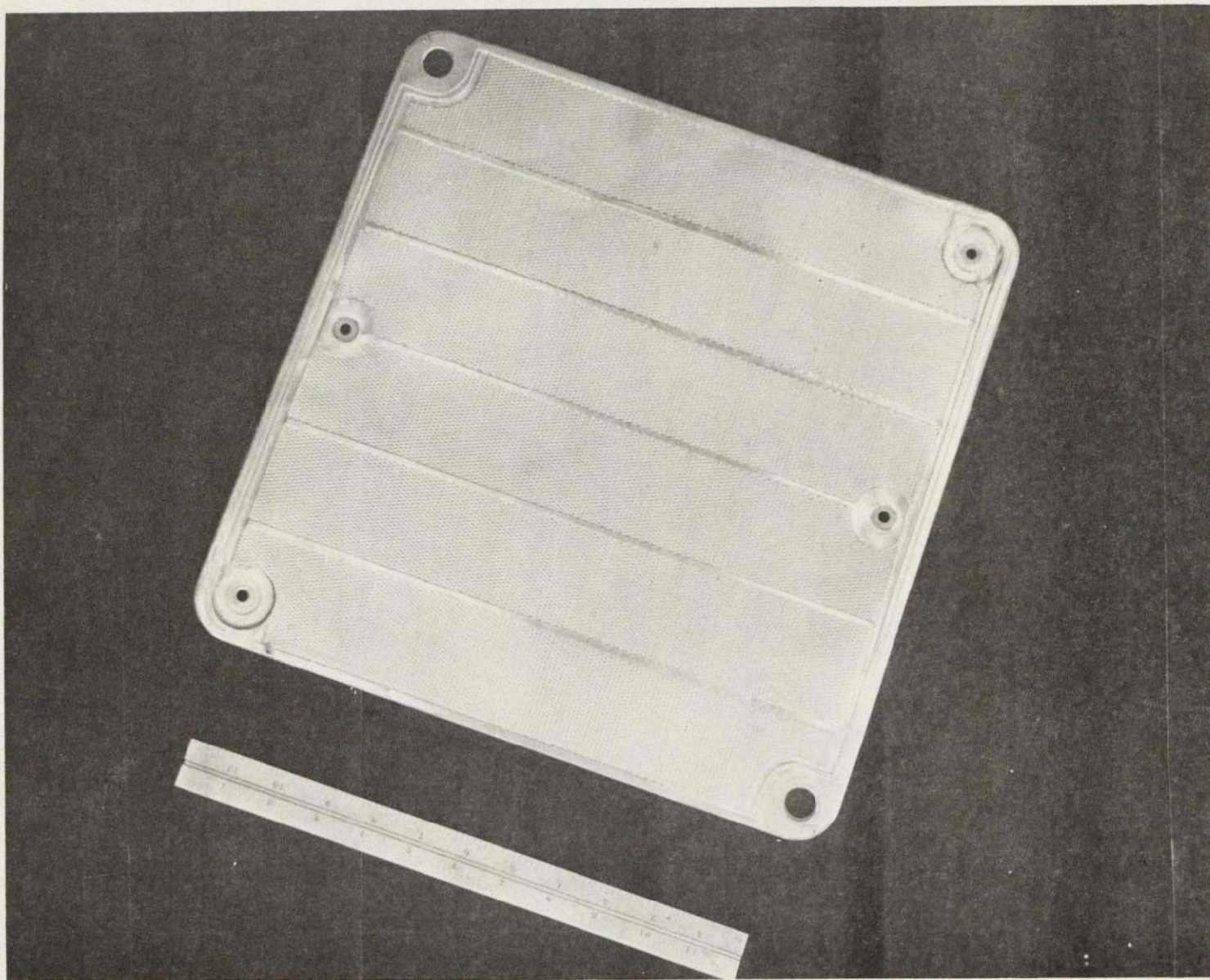


Figure 22. Completed Coolant Cartridge Showing Cathode Flow Field



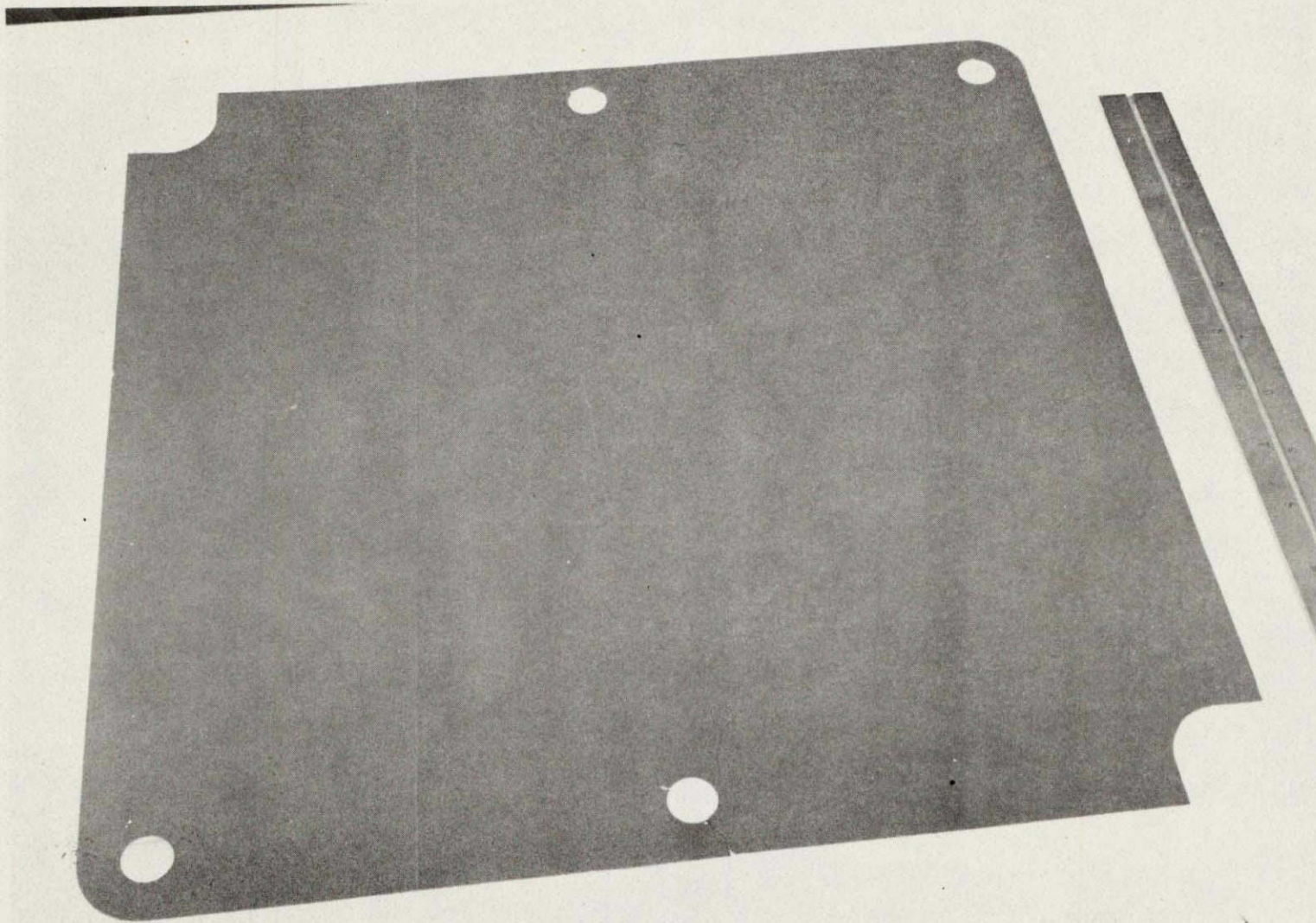


Figure 23. NASA Anode Flow Field Support

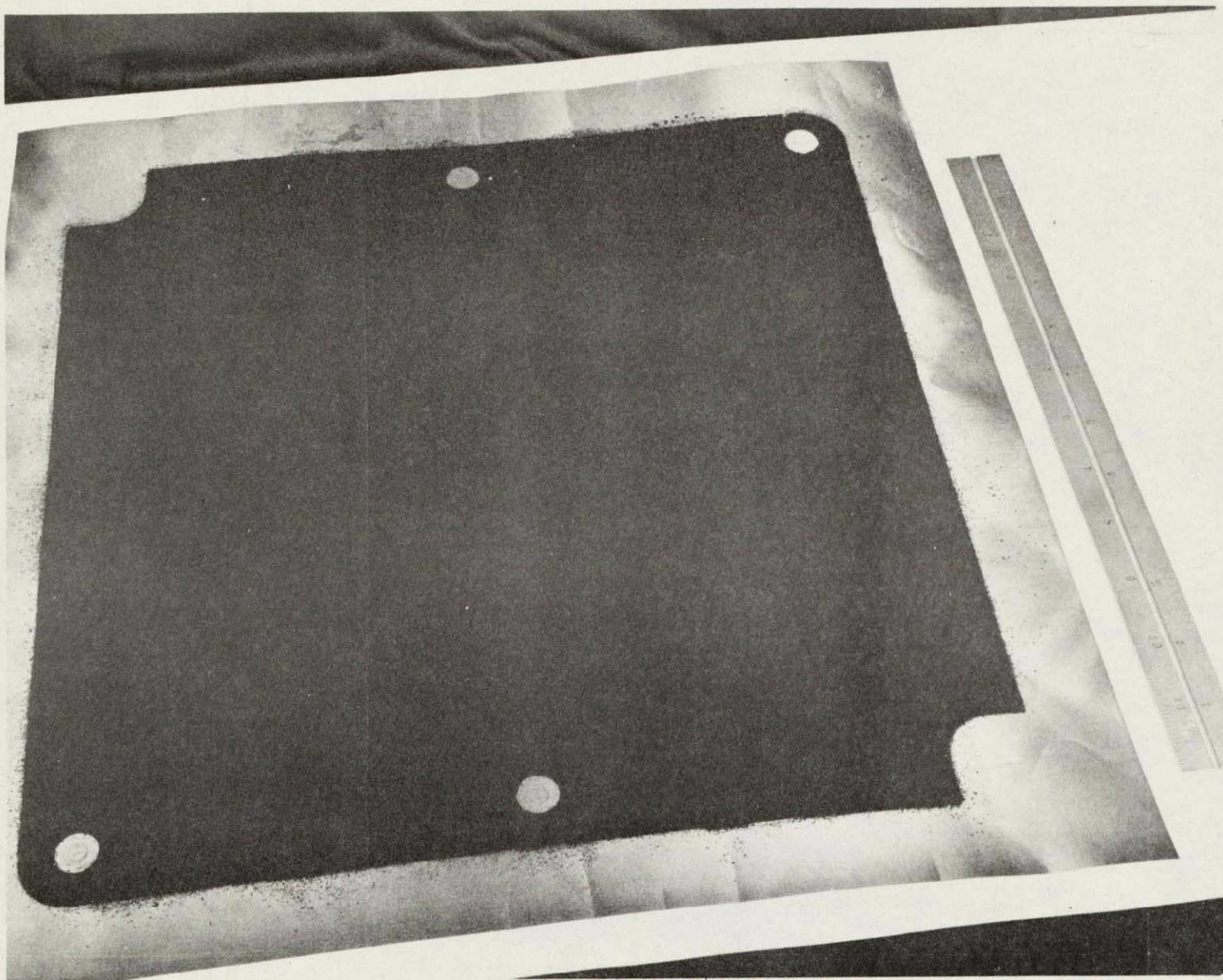


Figure 24. Catalytic Electrode for NASA 1.1 Ft² Cell



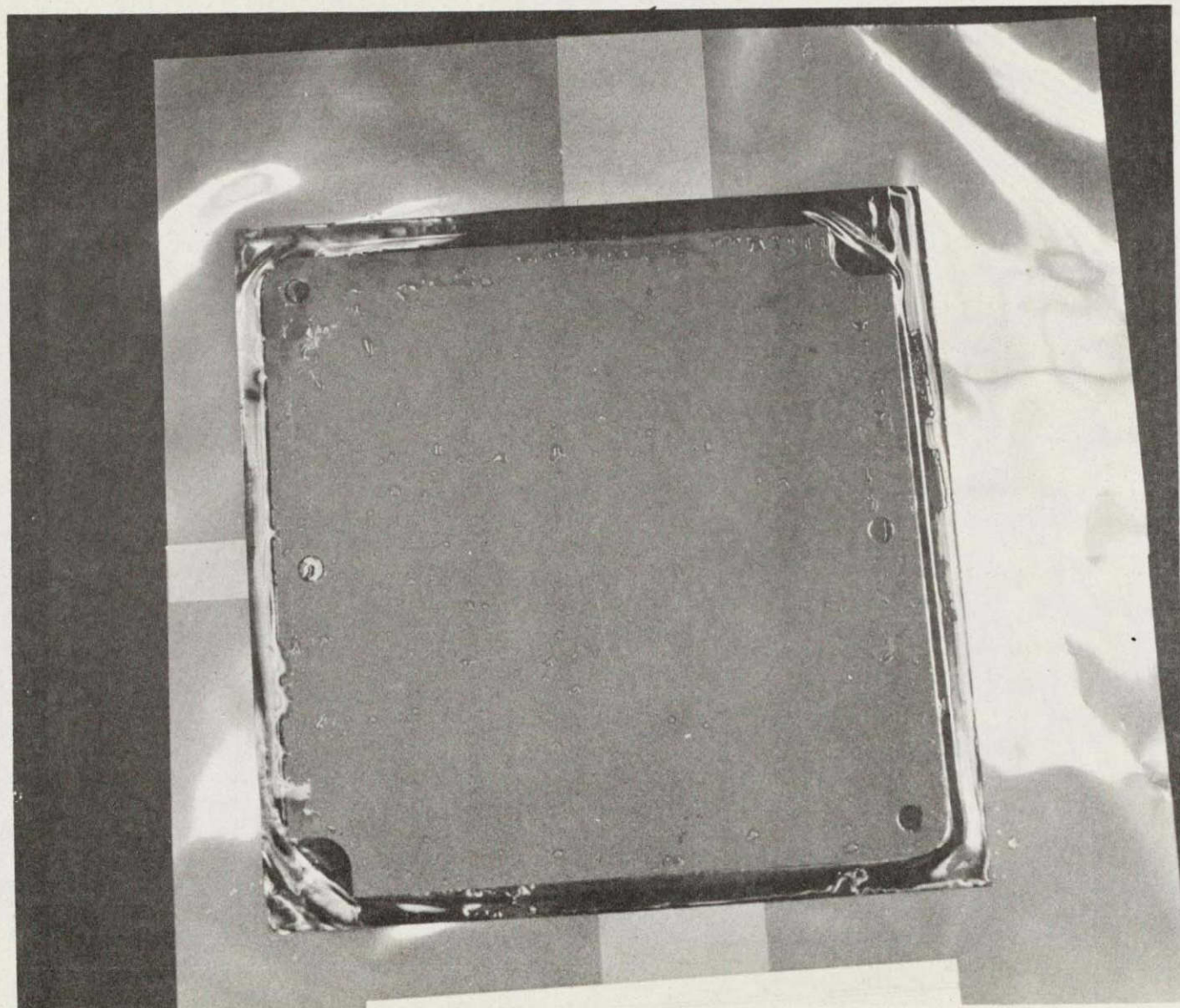
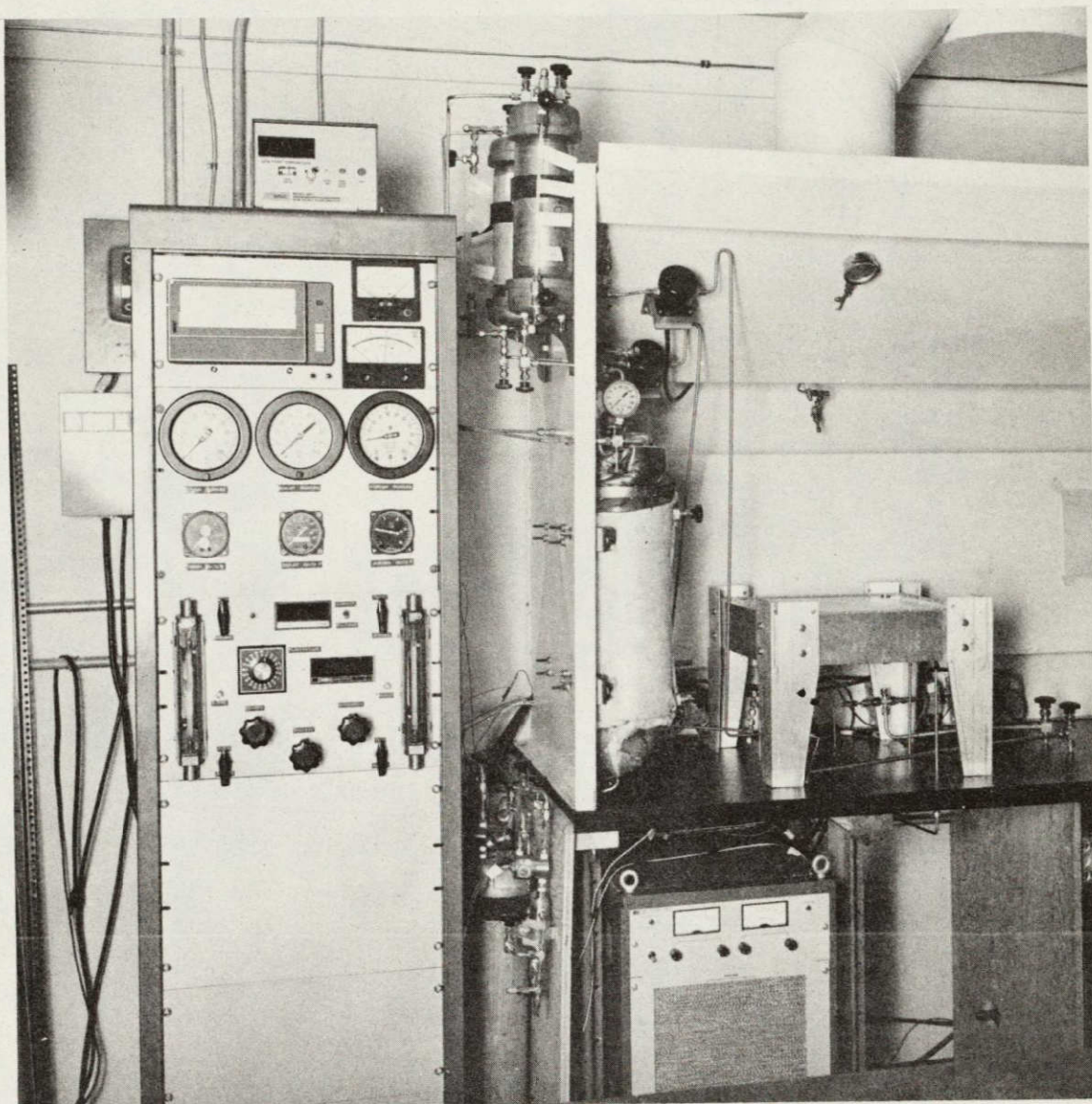


Figure 25. NASA Cell Assembly Showing Cathode Wetproofing Side





Buildup #01 Test Facility
Figure 26 .

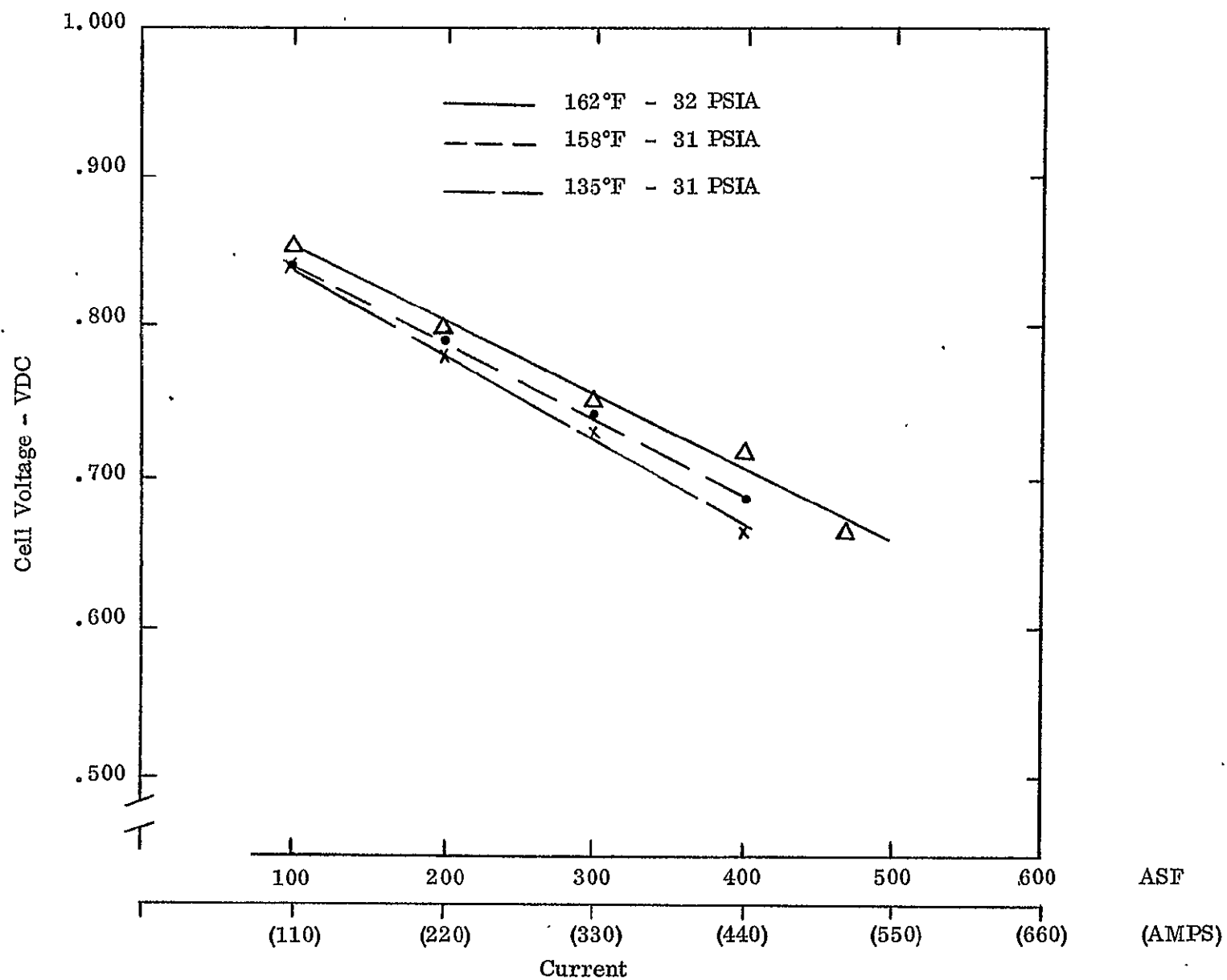
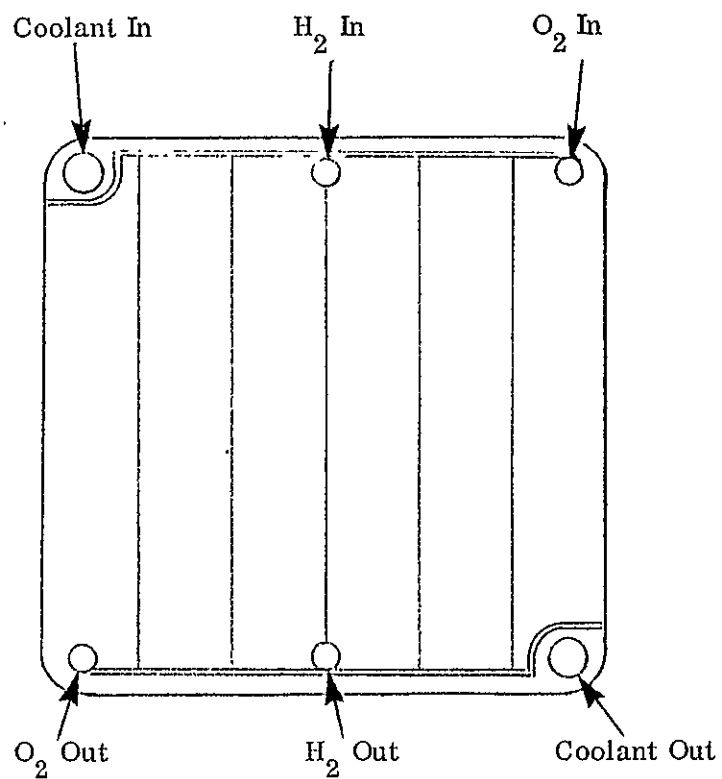
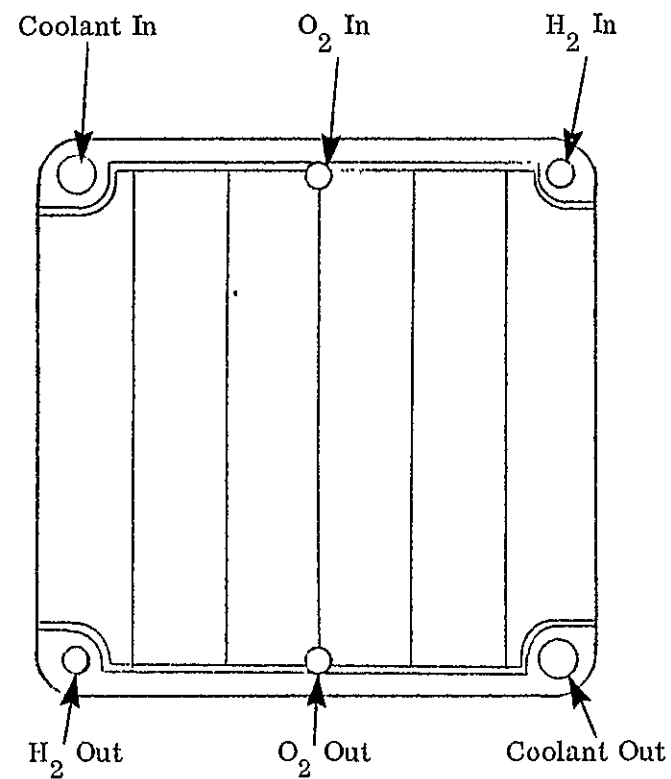


Figure 27. Build-Up No. 01 Performance Data





Current Configuration
(B/U #1)



New Configuration
(B/U #2)

Figure 28. Oxygen Flow Field Modification



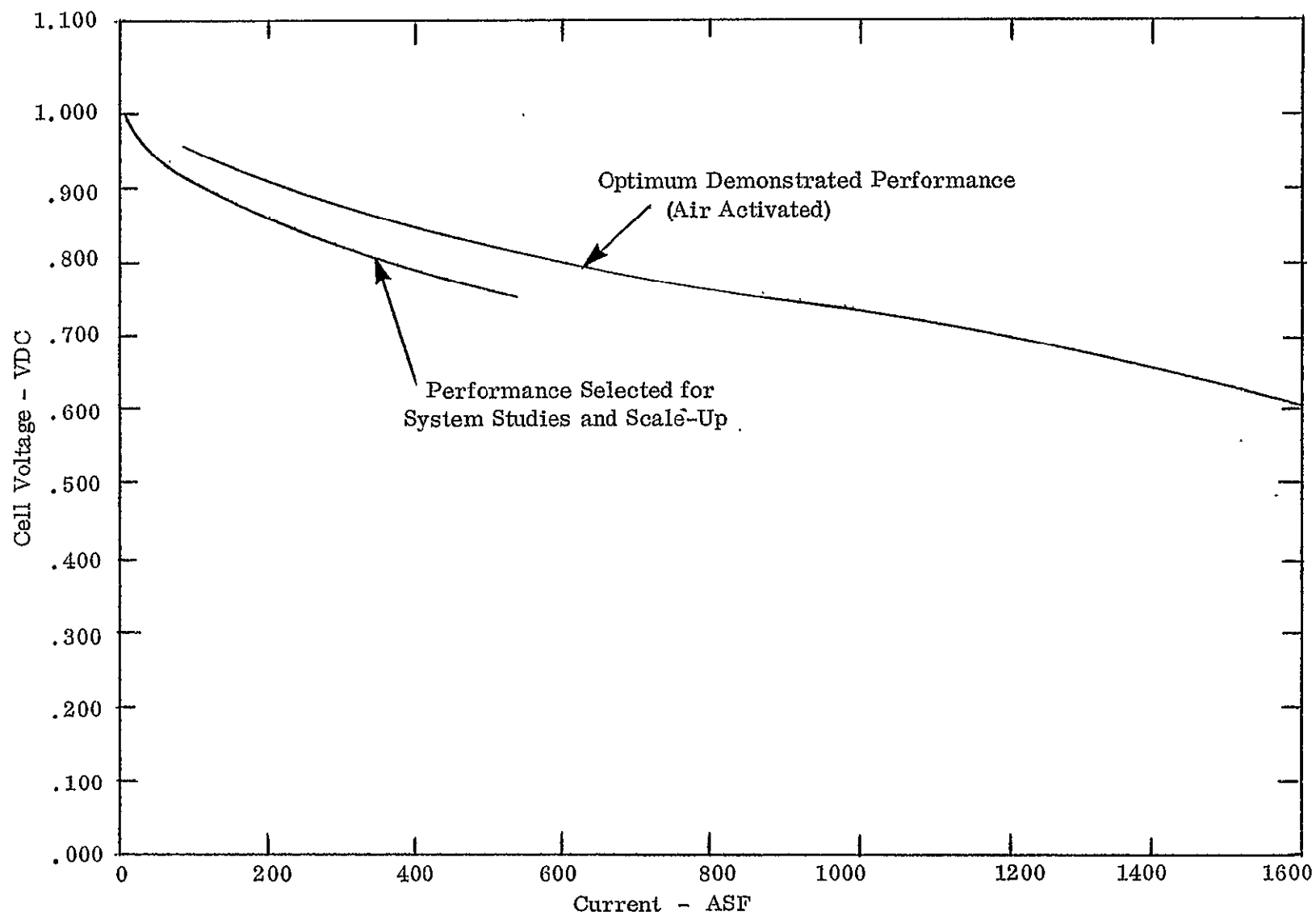
Figure 29. O_2/H_2 Performance

TABLE IX

SPACE SHUTTLE ENHANCEMENT PROGRAM

PROJECTIONS FOR VARIOUS VOLTAGE LEVELS OF FUEL CELLS

	28 VOLT	120 VOLT	270 VOLT
	<u>PROJECTIONS</u>	<u>PROJECTIONS</u>	<u>PROJECTIONS</u>
POWER RANGE	4-14 KW	4-14 KW	4-14 KW
CURRENT DENSITY	118-461 ASF	118-461 ASF	118-461 ASF
VOLTAGE RANGE	28-32.24 VDC	112-129 VDC	270-315 VDC
CELL AREA	1.1 FT ²	.275 FT ²	.12 FT ²
NO. OF CELLS	36	144	352
VOLUME	14" X 14" X 24"	8" X 8" X 40"	14" X 14" X 30" OR 7" X 14" X 48"
WEIGHT	150#	172#	246#
LIFE	>10,000	>10,000	>10,000
PRODUCTION COSTS	\$150 K	\$250 K	\$450 K
DEVELOPMENT COSTS	\$10 M	\$12 - 13 M	\$15 - 17 M
DEVELOPMENT TIME	2.5 -3 YEARS	3.0-3.5 YEARS	3.0-3.5 YEARS



TABLE X

SPACE SHUTTLE ENHANCEMENT PROGRAM

ADDITIONAL

PROJECTIONS FOR HIGH VOLTAGE/HIGH KW FUEL CELLS

270 VDC SYSTEM

	OPTION	OPTION	OPTION
	<u>#1</u>	<u>#2</u>	<u>#3</u>
POWER RANGE	2-16 KW	3-16 KW	4-16 KW
CURRENT DENSITY	20-163 ASF	40-235 ASF	72-300 ASF
VOLTAGE RANGE	256.5 - 283.5 VDC	256.5 - 283.5 VDC	256.5 - 283.5 VDC
CELL AREA	.388 FT ²	.269 FT ²	.210 FT ²
NO. OF CELLS	292	300	308
VOLUME	10" X 10" X 46"	9" X 9" X 49"	8" X 8" X 52"
	OR	OR	OR
	10" X 14" X 34"	9" X 14" X 35"	8" X 14" X 36"
WEIGHT	330#	290#	253#
LIFE	>10,000 HRS	>10,000 HRS	>10,000 HRS
PRODUCTION COSTS	\$390 K	\$400 K	\$410 K
DEVELOPMENT COSTS	\$14 - 16 M	\$14 - 16 M	\$14 - 16 M
DEVELOPMENT TIME	3.0 - 3.5 YEARS	3.0 - 3.5 YEARS	3.0 - 3.5 YEARS



display the effect of varying the range of power level. As the range becomes narrower (i.e., going from 2 - 16 KW to 4 - 16 KW), the major impact is a significant reduction in weight. This is due to the higher current densities and the resultant decrease in cell active area. Changes in other characteristics, such as cost, volume, and development time, are insignificant as a result of the power range variable.

Table XI displays two additional high voltage options (#4 + #5). Both of these options have a 14 KW peak and a 4 - 14 KW range. These characteristics are similar to the present space shuttle requirements. The option #4 configuration incorporates the $\pm 5\%$ voltage regulation, whereas option #5 considers a $+7.4\%/-6.7\%$ voltage range which is just slightly better than present space shuttle requirements. Once again, the major impact of allowing a slightly larger voltage range is in the reduced weight of smaller cell active areas by allowing increased current density.

The 270 volt, option #5 system seems to be particularly attractive as the volume, weight, power, power range and percent voltage regulation fall approximately within present space shuttle requirements, while providing the high voltage necessary for major weight reductions in the vehicle electrical busses. In addition, the long stable demonstrated life ($> 40,000$ hours at $< 1\mu$ volt/cell hour voltage decay) of the solid polymer electrolyte fuel cell will provide a useful life of $> 10,000$ operational hours.



TABLE XI
SPACE SHUTTLE ENHANCEMENT PROGRAM
PROJECTIONS FOR HIGH VOLTAGE FUEL CELLS
270 VDC SYSTEM

	OPTION <u>#4</u>	OPTION <u>#5</u>
POWER RANGE	4-14 KW	4-14 KW
CURRENT DENSITY	83-322 ASF	118-461 ASF
VOLTAGE RANGE	256.5 - 283.5 VDC	252 - 290 VDC
CELL AREA	.17 FT ²	.122 FT ²
NO. OF CELLS	310	324
VOLUME	7" X 7" X 52"	7" X 7" X 53"
	OR	OR
	7" X 14" X 36"	7" X 14" X 37"
WEIGHT	245#	216#
LIFE	>10,000 HRS	>10,000 HRS
PRODUCTION COSTS	\$410 K	\$420 K
DEVELOPMENT COSTS	\$14 - 16 M	\$14 - 16 M
DEVELOPMENT TIME	3.0 - 3.5 YEARS	3.0 - 3.5 YEARS



CONCLUSIONS

The conclusions realized during this Phase IV Technology Program can be summarized by the following statements:

- Life testing of laboratory cells and scaled-up cells has shown no uncorrectable malfunction mechanisms that would prohibit the establishment of a Solid Polymer Electrolyte fuel cell useful life in excess of 10,000 hours.
- A wide variety of energy storage options are available within the solid polymer electrolyte technology. These include dedicated and unitized H₂/O₂ regenerative systems, hydrogen/chlorine regenerative systems, and hydrogen/bromine regenerative systems. The optimum system will be dependent on the application requirements.
- Once again, the scale-up capability of the solid polymer electrolyte technology has been demonstrated by the performance of the first 1.1 Ft² unit (i.e., performance equivalent to laboratory hardware was demonstrated).
- From the space shuttle enhancement studies, a cost-effective, high voltage solid polymer electrolyte fuel cell appears probable within current space shuttle weight, volume, and percent voltage regulation requirements.



5.0 RECOMMENDATIONS

It is the recommendation of GE/DECP that the solid polymer electrolyte fuel cell technology program be continued beyond Phase V, currently in process. At the end of Phase V, the suitability of the advanced solid polymer electrolyte fuel cell technology for future space applications will be established. Refinements of this technology are recommended for a future Phase (Phase VI). The Phase V Program and the recommended Phase VI activities are summarized in the following paragraphs:

5.1 Phase V - Proposed Program

The proposed program for the Phase V technology advancement activities includes continued laboratory testing of 3 X 3 cells, full-scale small stack and reactor design, and small stack and reactor stack fabrications and evaluations. Figure 30 displays the schedule of the individual Phase V tasks. Details of the proposed program are as follows:

5.1.1 Task 1.0 - Laboratory Tests

The purpose of this task is to continue the endurance tests of laboratory 3 X 3 life tests which are in progress to establish additional confidence in the conductive wetproofing configuration. New endurance cells will be evaluated as deemed important to the overall program success. Design modifications that appear appropriate for the full-scale hardware will undergo checkout on the laboratory-scale 3 X 3 test hardware.

5.1.2 Task 2.0 - Single Cell Evaluation

This task includes the continuation of parametric and endurance testing of the single cell hardware which was designed, fabricated, and initially tested under Phase IV of the technology program. Modifications to this hardware may be incorporated for evaluation prior to incorporation into higher levels of stacks.

5.1.3 Task 3.0 - Small Stack Evaluation

This task is divided into two sub-tasks. One sub-task consists of the fabrication of a small stack, and the second sub-task concerns facility preparations and test evaluation of the small stack.

5.1.3.1 Sub-Task 3.1 - Hardware Fabrication

In this sub-task a four-cell stack with appropriate non-flight end plates, terminal plates, etc., will be fabricated and be subjected to non-operational check-out tests. Tests to be performed include:

- Leakage tests
- Flow tests
- Electrical tests



NASA/JSC SOLID POLYMER ELECTROLYTE FUEL CELL TECHNOLOGY PROGRAM

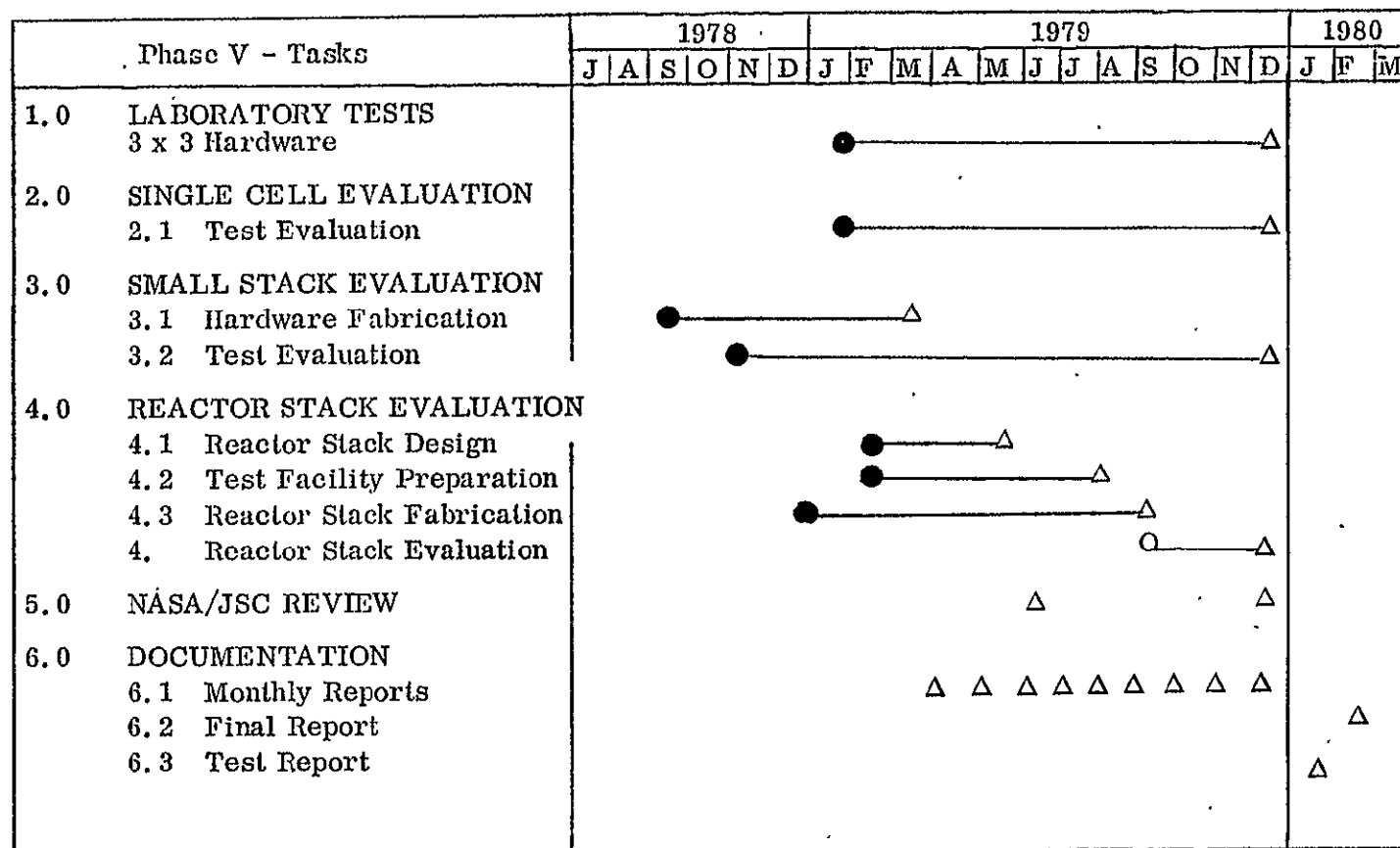


Figure 30.



The active area of configuration of the individual cells will be of the type developed under the single cell evaluation tasks of Phases IV and V. The sizing of this hardware includes an active area of 1.1 Ft² for each cell. The individual fuel cell assembly will consist of a membrane and electrode assembly and fluid separator assembly. The membrane will be approximately .005-inch thick Nafion film with platinum electrodes pressed into each side. Noble metal loading on each electrode will be at a level of 4 grams/Ft². A conductive wet-proofing film will be attached to the cathode electrode to facilitate water removal and current collection. An uncatalyzed portion of the membrane will extend to the outer frame edge and around the fluid manifold ports of the fluid separator assembly. This extended membrane provides the gasket seal both around the perimeter and around the fluid manifolds within the cells and compressed between end plates.

The fluid separator assembly is a welded niobium assembly which provides flow paths for coolant, oxygen, hydrogen and product water. The coolant cavity is supported by a titanium truss. The two plates are embossed with a flow pattern for the hydrogen, oxygen and product water flow.

The dry weight of the individual cell assembly will be approximately 1.3 pounds. Total cell weight with coolant will be approximately 1.7 pounds.

The end plates for this four-cell stack will be of the boiler plate type with all attendant functional aspects; however, no attempt will be made to optimize for weight and volume.

5.1.3.2 Sub-task 3.2 - Test Evaluation

Existing DECP facilities will be modified to provide the capability of operating the hardware produced in sub-task 3.1. The facilities will include provisions for reactant prehumidification and unattended operation. These facilities will be checked out prior to use with the four-cell stack.

The four-cell stack will be activated and operated at various temperatures, pressures and current densities to allow direct performance comparison to the 3 X 3 cell data. Endurance testing will be performed on the unit following the collection of parametric data.

Preliminary set of conditions for the endurance testing is as follows:

- Current density 100 - 500 ASF
- Pressure 115 psia
- Temperature 175 - 185°F

The preliminary conditions are within the range of the demonstrated 40,000 hour life and were selected for that primary reason. As 3 X 3 test results indicate endurance capabilities at more optimum conditions, these will be factored into the test plan. Even at these somewhat conservative operating conditions, a power output of over 400 watts per cell will be generated. The wet cell weight (not including end plates or ancillaries) will be approximately 4 pounds/KW.



5.1.4 Task 4.0 - Reactor Stack Design

This task is divided into four sub-tasks with the overall objective of demonstrating a multi-KW stack.

5.1.4.1 Reactor Stack Design

The three major stack components for the reactor stack include:

- Cell assemblies
- End plate
- Central fluid plate (reactant humidifier)

The cell assembly design for the multi-KW reactor stack will be established in the evaluations of the single cell hardware and the four-cell stack hardware. In the single cell design task of Phase IV, the cell integral manifold porting was sized to accommodate the flow of as many as 72 cells on either side of the central fluid plate.

The end plate design will be completed as part of this sub-task. The basic concepts to be utilized for this end plate will be related to the end plates developed for the Navy Aircraft Oxygen Generation Stack (NOBOGS). This end plate utilized a pressurized chamber which applied a sealing and active area force on the cells at approximately 75 psi above maximum operating pressure (i.e., approximately 400 psi).

The central fluid plate with built-in reactant humidifiers will also be designed as part of this sub-task. The concepts utilized will be a combination of previously successful designs (i.e., the common feed plate of NOBOGS, and the end plate reactant humidifier of the NASA/JSC technology program for space shuttles).

5.1.4.2 Sub-task 4.2 - Test Facility Preparation

Test facilities will be prepared for the unattended operation of the multi-KW reactor stack. The major facility functions will include:

- Pressure, temperature and flow controls for oxidant, fuel and coolant.
- Variable load bank.
- Continuous recording of temperatures.
- Continuous recording of voltage and current.
- Controls for steady-state automatic operation with safety shutdowns.

The facility will undergo a complete checkout prior to installation of the reactor stack. These checks will include:



- Subsystem leakage checks
- Flow and pressure control checks
- Electrical subsystem operation and checkout.

5.1.4.3 Sub-task 4.3 - Reactor Stack Fabrication

The reactor stack as presently conceived could include up to 18 cell assemblies, one flight weight pressurization end plate, and a central fluid plate. A built-in reactant humidifier will also be incorporated if practical within the scope of the program. A boiler plate end plate will substitute for the "second half" of the reactor stack. This arrangement allows full-sized reactor stack fluid flow evaluations with the economy of requiring only half a stack. (See Figure 31.)

Complete checkout of the end plate and central fluid plates will be performed before integration with the cell assemblies. These checks will include:

- Pressure tests
- Flow and leakage tests
- Humidification tests

The assembled reactor stack will then undergo leakage and electrical checks. Electrical checks will include shunting and internal resistance measurements.

5.1.4.4 Sub-task 4.4 - Reactor Stack Evaluation

The fuel cell reactor stack will be installed in the facility. Flow, leakage and electrical checks of the facility/stack integration will be performed. Once these checkouts are successfully completed, the reactor stack will be activated and a series of parametric tests performed.

The reactor stack will be subjected to an endurance run following the parametric testing. Two thousand hours of endurance testing will be the goal of the reactor stack operation.

5.2 Phase VI - Proposed Program

The objectives of the recommendations for Phase VI are to extend the demonstrated capabilities of the 1.1 Ft² cell design and to evaluate refinements that potentially increase these capabilities. The following tasks shown on Figure 32, Program Milestone Chart, would be configured to support the overall phase objectives.

5.2.1 Task 1.0 - Laboratory Tests

Under this task, 3 X 3 laboratory cells would be configured and operated to establish initial life characteristics on refined configurations. These configurations will include advances in wetproofing designs and modest increases in Nafion ion conductivity.



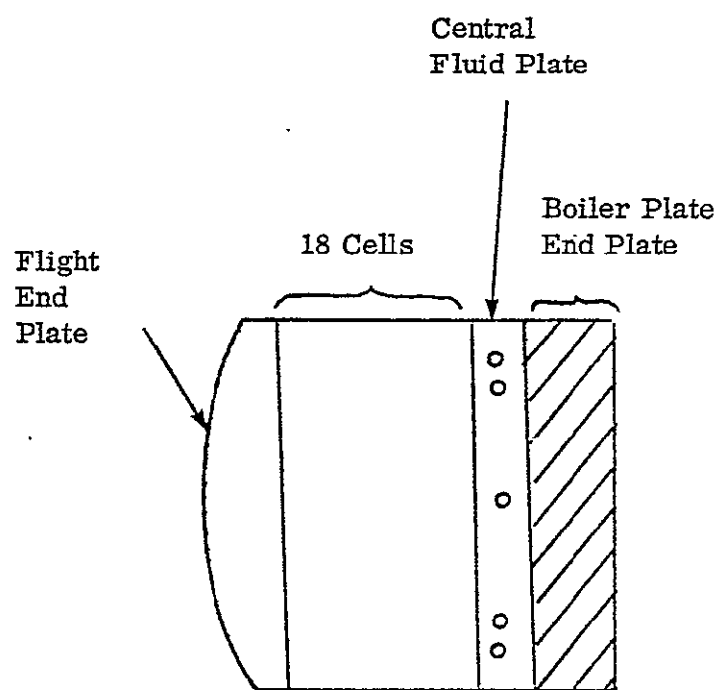


Figure 31. Reactor Stack Assembly

NASA/JSC SOLID POLYMER ELECTROLYTE FUEL CELL TECHNOLOGY PROGRAM

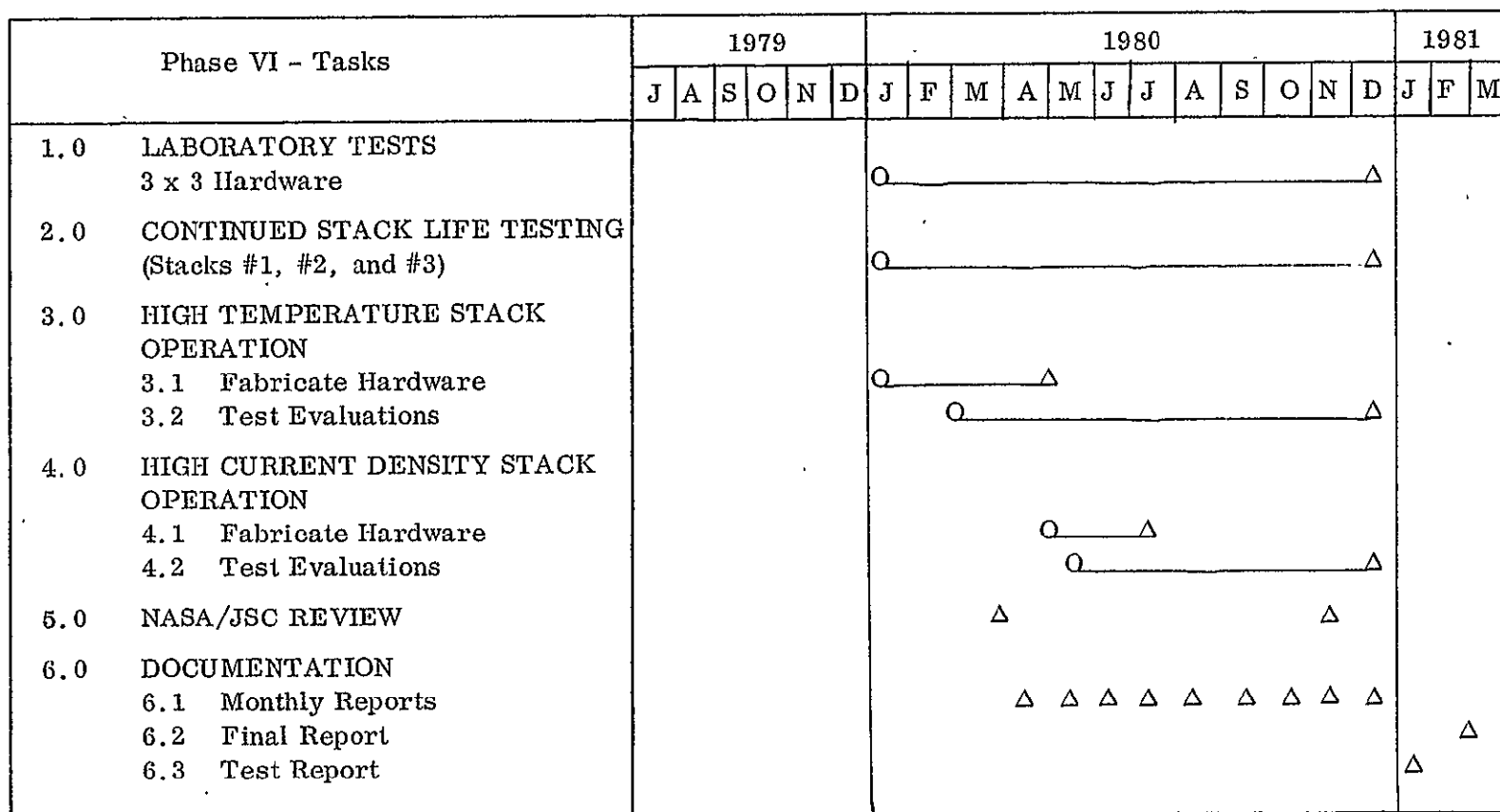


Figure 32. Milestone Chart



5.2.2 Task 2.0 - Continued Stack Life Testing

In this task, the three 1.1 Ft² cell stacks evaluated in Phases IV and V will be continued in endurance testing to establish increased confidence in the IEM capabilities.

5.2.3 Task 3.0 - High Temperature Stack Operation

Previous studies indicated that an optimum weight-effective system, including radiators and reactant supplies, is established by a solid polymer electrolyte fuel cell operating in the temperature range of 220°F to 240°F. In this task, a 4-cell (1.1 Ft² each) stack and test facility would be configured for parametric evaluation and endurance testing in the 220°F to 240°F temperature range.

5.2.3 Task 4.0 - High Current Density Stack Operation

During the earlier technology phases, significantly improved voltage characteristics were demonstrated with slight increases in the Nafion ion conductivity. This characteristic was not selected for the initial 1.1 Ft² cell design due to lack of experience with this configuration. This task will incorporate a higher ion conductivity Nafion electrolyte along with any demonstrated conductive wetproofing improvements into a 4-cell (1.1 Ft² each) stack. The operational goal of this stack on a newly assembled test facility will be the demonstration of peak power capabilities in the 700 to 1000 ASF range.



APPENDIX A

COMPLEMENTARY RESEARCH AND
DEVELOPMENT PROGRAMS



NASA/JSC FUEL CELL TECHNOLOGY PROGRAM

Complementary Research and Development Programs

There are research and development programs currently underway to GE/DECP which are related to the fuel cell technology development effort and which represent significant potential beneficial spin-offs to the NASA/JSC fuel cell technology program. Several of these efforts are funded through the IR and D Program or internal Future Benefit Programs, while others are funded through contracts with other Government agencies or Industrial Corporations. Summarized below are the most significant of these efforts currently in process:

1. Evaluation of life capabilities of fuel cells operating on O_2/H_2 and air/ H_2 in the 30,000 to 60,000 hour range. (GE IR&D)
2. Evaluation of the technology needed to run electrolysis cells for life at current densities in the range of 2,000 to 6,000 ASF. (GE IR&D)
3. Evaluation of cell life capabilities under conditions of increased operating temperature (240 to 300°F). (Industry)
4. Development of alternate cathode conductive wetproofing configurations with improved electrical and mechanical characteristics. (GE IR&D)
5. Development of lower catalyst loadings on both anode and cathode to reduce material costs by a factor of 6 to 8. (Industry)
6. Scale-up of manufacturing capabilities and evaluation of process flow and equipment development needed to reduce labor involved in fabrication of membrane and electrode assemblies by a factor of 2 to 3. (GE/DECP)
7. Improve platinum plating procedures employed on current collectors to reduce high contact resistances associated with long-life capabilities. (GE IR&D)
8. Evaluation of starting and stopping procedures for fuel cells utilizing gas switching techniques. Start-up in a few milli-seconds is the goal. (GE IR&D)
9. Evaluation of alternative high-stress frame materials to develop a more effective cell sealing capability. (GE IR&D)
10. Development of a cell failure isolation device. A significant cost impact results when requiring the replacement of only one cell of a multi cell stack in the unlikely event of a cell cross-leak. (GE IR&D)

